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A cost and operational effectiveness analysis of alternative anti-surface warfare platforms

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A COST AND OPERATIONAL EFFECTIVENESS ANALYSIS
OF ALTERNATIVE ANTI-SURFACE WARFARE PLATFORMS

by

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June 1993

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A Cost and Operational Effectiveness Analysis (COEA) is performed for three alternative anti-surface warfare (ASUW) platforms that will conduct operations in multi-service regional scenarios. Estimated program costs, historical cost variances, and measures of operational effectiveness are determined for each COEA alternative, and service life extension effects are examined. The data is merged in a mixed-integer optimization model, MPAMOD1, that develops the best implementation plan for each alternative. The solution of choice is an ASUW Improvement Program modified P-3C whose service life is extended through a Sustained Readiness Program. Historical cost variance of P-3C cost estimates proves inconsequential over the planning horizon. A second question is then examined, that of the cost effectiveness of major modification programs versus new production aircraft. Cost effectiveness of major modification programs becomes doubtful only when modification costs exceed 150% of original cost estimates.

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ABSTRACT

A Cost and Operational Effectiveness Analysis (COEA) is performed for three alternative anti-surface warfare (ASUW) platforms that will conduct operations in multi-service, regional scenarios. Estimated program costs, historical cost variances, and measures of operational effectiveness are determined for each COEA alternative, and service life extension effects are examined. The data is merged in a mixed-integer optimization model, MPAMOD1, that develops the best implementation plan for each alternative. The solution of choice is an ASUW Improvement Program modified P-3C whose service life is extended through a Sustained Readiness Program. Historical cost variance of P-3C cost estimates proves inconsequential over the planning horizon. A second question is then examined, that of the cost effectiveness of major modification programs versus new production aircraft. Cost effectiveness of major modification programs becomes doubtful only when modification costs exceed 150% of original cost estimates.

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I. INTRODUCTION

The Department of Defense (DOD) approaches the 21st century facing critical decisions involving the composition of future armed forces. DOD managers must shape, from a group of disparate options, a force structure that balances combat effectiveness and cost while still meeting mission needs. This thesis examines part of one resource allocation decision involving alternative anti-surface warfare (ASUW) platforms. These platforms are required for use in multi-service, limited area, shallow water operations.

The DOD Cost and Operational Effectiveness Analysis (COEA) process is used to examine several variants of three alternative ASUW platforms currently being considered: existing, modified, and new production P-3 maritime patrol aircraft. This thesis first develops detailed cost estimates, which incorporate historical cost variance calculations. The cost estimates are merged with measures of operational effectiveness (MOE) in an optimization model. The model maximizes P-3 fleet effectiveness subject to budget limitations and annual inventory, MOE, and average fleet age goals. It then provides a schedule for modification implementation or new aircraft procurement.

After the best COEA alternative is determined, a new question is examined. The model is used to compare the cost

effectiveness of modified versus new production P-3 aircraft. In particular, the effects of different service lives and procurement costs on life cycle costs are evaluated.

A. AIRCRAFT PROCUREMENT AND FISCAL REALITY

By 1997, the defense budget, as proposed, will experience a 41% real decline compared to the peak year of the Reagan defense buildup, fiscal year 1985 (FY 1985) [Ref. 1]. As world tensions between major powers ease and emphasis is placed on solving domestic problems, actual FY 1997 defense spending could fall to much lower levels [Ref. 2].

Weapon systems procurement comprises a sizable portion of the defense budget. As expected, the DOD procurement budget has also declined precipitously since 1985, from a high of $115 billion in constant 1985 dollars to approximately $60 billion in 1992 [Ref. 3]. The procurement budget cuts caused termination of ongoing acquisition programs, such as the Army's Apache helicopter and the Air Force's F-15E aircraft, before follow-on systems were available. Other programs experiencing acquisition problems, such as the Navy's A-12 and P-7 aircraft programs, have been cancelled outright before production.

The DOD procurement budget cuts are occurring when Naval aircraft procurement needs are increasing due to aircraft obsolescence and aging. According to the Congressional Budget Office (CBO) [Ref. 4], the Aircraft Procurement Navy (APN)

accounts have experienced an average real growth of 7% annually from 1987 through 1992. They will stabilize in 1994 at approximately 9.5 percent of total DON budget authority [Ref. 5], yielding approximately $6 billion for aircraft procurement and modification. Shortfalls of 176 fighter and attack aircraft are projected during this same time period, based on aircraft requirements for 15 aircraft carriers. Even with reduced aircraft needs given fewer aircraft carriers (a reduction to 12 by FY 1994 is proposed [Ref. 1]), effective use of APN dollars is paramount as Naval Aviation struggles with the conflicting requirements of aircraft type, quantity, effectiveness, cost, and age.

As budget resources become scarcer, effective allocation tools gain in importance. The COEA is one tool that encourages the effective resource allocation needed to deal with these requirements.

B. THE COST AND OPERATIONAL EFFECTIVENESS ANALYSIS

The use of the COEA is endorsed by the Office of the Assistant Secretary of Defense for Program Analysis and Evaluation, ASD(PA&E) [Ref. 3]. Three major points are stressed by ASD(PA&E):

- DOD managers should use COEAs to help understand the effects of different technological solutions in terms of military capabilities and payoffs.
- DOD managers should use realism in assessing program prospects, because future acquisition programs

experiencing difficulties will face termination instead of DOD assistance.

- DOD managers should maintain the ability to adopt different courses of action while executing a program within budget totals.

The COEA is a useful tool that is supposed to address all three points made by ASD(PA&E). It is prepared and considered at milestone decision reviews of all acquisition programs, beginning with Milestone I, Concept Demonstration Approval [Ref. 6]. The COEA ideally aids decision making by illuminating each alternative's relative cost and operational advantages and disadvantages, through comparisons of life cycle costs[1] and measures of operational capabilities. It also shows sensitivity to possible changes in key assumptions and variables. The COEA also attempts to facilitate communications among decision makers and staffs and document acquisition decisions by providing a historical record of alternatives considered at each milestone decision point.

The COEA is comprised of several sub-analyses, as depicted in Table I [Ref. 6]. This thesis examines COEA cost, cost-effectiveness comparison, and sensitivity analysis areas for three P-3 aircraft alternatives tasked with conducting ASUW in a joint (multi-service), littoral (shallow water) scenario.

[1]Life cycle costs are defined as the sum of the following costs: program flyaway costs (procurement cost of basic unit, recurring and non-recurring production costs, and recurring system project management); training and support equipment cost; cost of initial spares; research, development, test and evaluation costs; military construction costs; and operation and maintenance costs.

The P-3 alternatives are a subset of the options that meet this particular DOD mission need. Other DON commands will examine other options, such as unmanned air vehicles or satellite based systems.

TABLE I
COEA SUB-ANALYSIS AREAS

Sub-Analysis Area	Definition
Mission Need Analysis	Identifies forces to meet specific operational need.
Threat Evaluation	Describes projections of enemy threat over time.
System Interrelationships	Evaluates interoperability of system with current forces.
Multi-Role Systems	Evaluates ability of system to conduct different functions.
Measures of Effectiveness (MOE)	A measure of operational capabilities in terms of battle outcomes.
Costs	Measures resource inputs over system life-cycle.
Cost-Effectiveness Comparison	Examines marginal change in MOEs and costs on an equal cost or equal effectiveness basis.
Sensitivity Analysis	Highlights effects of changes in threat, key performance criteria, or other baseline parameters.

C. THE PROPOSED PROGRAM AND METHODOLOGY

As a result of lessons learned in Operation Desert Storm and guidance promulgated in the Department of the Navy (DON) 1992 White Paper "...From the Sea" [Ref. 7], a mission need has originated for additional ASUW platforms. The DON White

Paper notes that our National Security Strategy has shifted from an emphasis on global threats and traditional independent blue water Navy roles to one focused on regional challenges in joint, littoral scenarios. It defines the heart of naval warfare as battlespace domination and states that ASUW, performed traditionally by battle groups, is an integral part of this mission. In light of declining defense budgets and reduced traditional assets, DON is exploring alternative ASUW platforms and mixes. By utilizing the COEA to examine mission costs and tactical effectiveness, DON can select the best alternatives to perform the ASUW mission.

The COEA alternatives examined in this thesis are platforms currently being considered for the alternative ASUW role. The alternatives, depicted in Table II, all involve the Navy's Maritime Patrol Aviation (MPA) force composed of Lockheed P-3 Orion aircraft.

TABLE II
ASUW COEA ALTERNATIVES

Alternative 1 CURRENT P-3 FORCE	Existing P-3s - the Status Quo
Alternative 2 P-3 AIP PROGRAM	Existing P-3s with Minor Avionics Upgrade
Alternative 3 ORION II PROGRAM	New Production P-3

All alternatives are capable of conducting ASUW search, location, tracking, and attack operations in littoral

scenarios and passing real-time information to a higher authority that is commanding joint forces. Each COEA alternative is evaluated using MOEs developed by NAIR-526, the Naval Air Systems Command (NAVAIRSYSCOM) Warfare Analysis Division [Ref. 8], and author-developed "analogous" life cycle cost estimates.

The COEA's sensitivity analysis concentrates on the effects of increased aircraft service life and cost variance. Service life effects are examined using two P-3 life extension programs, the Sustained Readiness Program (SRP) and the Service Life Extension Program (SLEP). Cost variance effects for the modification and new aircraft program are studied using data extracted from Selected Acquisition Reports (SAR)[2] by the author and RAND Corporation [Ref. 9].

Given the COEA requirement to evaluate the three P-3 alternatives using the MOEs, cost estimates, and sensitivity analyses previously mentioned, an analytical tool is needed that compares each alternative while considering the overall effects of its choice on the entire P-3 fleet. The most effective, or optimum plan, would meet the COEA mission need and be readily supported by and integrated into the current P-3 force structure.

[2]The SAR is used by Congress to monitor the cost of major DOD weapons acquisition programs, and is required by Section 2432, Title 10, of the United States Code. SARs are governed by DOD Instructions (DODI) 5000.2 [Ref. 6] and 5000.2-M [Ref. 10].

MPAMOD1 (MPA MODernization model, version 1), a mixed-integer optimization model, is a tool that can accomplish this task. MPAMOD1 determines an effective multi-year plan for implementation of each P-3 alternative while establishing constraints to ensure, if possible, that:

- Required P-3 fleet inventory levels are maintained,
- Minimum ASUW MOEs are met,
- Maximum average P-3 fleet age is not exceeded,
- Program expenditures remain within budget limits, and
- Minimum and maximum program production line limits are not violated.

MPAMOD1 is a modified "production/inventory" model. A similar model, the "PHOENIX" model, was used to analyze the Army's helicopter fleet modernization program [Ref. 11]. MPAMOD1 determines optimal schedules for aircraft modification and/or new production, and existing aircraft retirements. It also provides annual totals for budget expenditures, aircraft inventory levels, average P-3 fleet ASUW effectiveness, and average P-3 fleet age. MPAMOD1 provides the output necessary to evaluate each COEA alternative's effect on the entire P-3 fleet, providing the "best possible" implementation plan. Thus, a level "playing field" is established for all alternatives.

After the best COEA alternative is determined, a second question is examined. The model is used to address the cost effectiveness of major aircraft modification programs,

assuming that the modified aircraft service lives are not extended. A new production P-3 with a longer airframe service life is compared to modifying existing P-3s, which have shorter service lives. The modified P-3s have lower initial costs than the new aircraft, and both have the same mission systems installed.

D. THESIS OUTLINE

Chapter II reviews the background and history of the weapon system cost estimates, SAR-based sensitivity analysis, and optimization models similar to MPAMOD1. Chapter III describes the cost estimates for the three basic COEA alternatives and the two life extension programs that can modify the alternatives. The cost estimate for the P-3 modification involved in the airframe service life analysis is also presented, and all estimates are examined for validity using historical program data. Chapter IV details the SAR-based sensitivity analysis and establishes a cost variance factor to improve cost estimate accuracy. Chapter V describes MPAMOD1 and its assumptions along with a description of input data required by the model. Chapter VI details the nine separate scenarios that are modeled and run to determine the best COEA alternative. The effects of the P-3 life extension programs and the alternatives' sensitivity to changes in cost are also examined. In addition, the airframe service life analysis (major modification versus new aircraft) is

presented. Chapter VII discusses conclusions, recommendations, and areas for further study.

II. BACKGROUND AND HISTORY

A. INTRODUCTION

A comprehensive body of literature exists that addresses cost estimation techniques, cost estimate variance, and optimal resource allocation for weapon systems. This thesis builds on historical efforts dating back more than 30 years, predominately by government sponsored research organizations such as RAND and the Institute for Defense Analyses (IDA). Private contractors and academic institutions have also played their part. Their past efforts provide fertile ground to determine a method for estimating the minimum life cycle cost of the three P-3 ASUW COEA alternatives, and to improve subsequent estimate accuracy.

The chapter opens by examining the literature associated with cost estimation techniques for aircraft modification and new aircraft procurement programs. Techniques for determining cost variance are described next, followed by a discussion of the history of the optimization model.

B. WEAPON SYSTEM COST ESTIMATION TECHNIQUES

The literature was examined to determine which of the three common cost estimation techniques, "parametric", "analogous", or "engineering" (all defined below), would be best for costing the P-3 avionics modifications and new

aircraft alternatives for the COEA. Ideally, COEA cost estimates should be accurate enough to determine relative cost differences between numerous alternatives despite the lack of detailed information available in a program's early stages. Parametric cost estimation techniques meet the criteria stated above, and are defined by Michael G. Sovereign as follows:

> The top down [parametric] approach has the advantage of being available early when decisions on configuration of the product are still being made, i.e., in the design stage. It uses statistically estimated, logical relationships between the cost per unit of product and the physical and performance characteristics (or parameters) of the product, i.e., weight, speed, etc. [Ref. 12]

Parametric approaches seem ideally suited for the COEA cost estimation process, as opposed to the analogous or engineering techniques, and the vast quantity of literature available primarily addresses this technique.

Sovereign defines the analogous method as an early, crude estimate that is made by picking the closest existing analog to the proposed system [Ref. 12]. Analogous cost estimates can be generated from historical cost data for entire systems or from task elements of previous systems. They require keen judgment by the cost analyst, because correction factors must be developed and applied to successfully compare the historic costs of older systems to new systems.

Finally, the engineering method is defined as:

> [An] approach...only available from the detailed input calculations of the industrial engineers and cost

accountants many months or years after the initial cost estimates are made. [Ref. 12]

Because engineering cost estimates require large historical data bases and long preparation times, they are unsuitable for early COEA cost estimates. The literature search, therefore, focuses on parametric and analogous models.

1. Aircraft Modification Cost Estimation Techniques

There have been numerous studies, undertaken primarily by the RAND Corporation, addressing the problems of aircraft modification cost estimation. In 1978, RAND evaluated nine existing life-cycle cost preliminary planning models for the United States Air Force to determine their effectiveness in evaluating aircraft modification costs. The RAND study concluded that the models had many shortcomings and were of limited use [Ref. 13].

In two separate 1981 studies, RAND attempted to develop parametric Cost Estimating Relationships (CERs) for both avionics systems and aircraft structural modifications. The pursuit of avionics CERs proved largely unsuccessful [Ref. 14], as did the search for aircraft structural modifications CERs [Ref. 15], which proved unreliable when compared to the actual costs of known modification programs. In each case, however, the RAND models yielded improvements over then-current estimation techniques. Despite lack of major success, the avionics CERs were more accurate than an earlier "cost per pound method" and the aircraft modification CERs proved useful

when applied with discretion and an understanding of original production history.

In 1987, the General Accounting Office (GAO) [Ref. 16] issued a report pertaining to the United States Air Force's B-52, A-10, and F-111 modification programs. The report noted that the programs were over funded due to high original modification cost estimates. The B-52 program, for example, accumulated $323 million in excess funds alone by obligating only 86% of total funds appropriated for modifications. DOD and Air Force officials justified the anomaly as follows:

- Original estimates are based on contractors' "rough order of magnitude" estimates, with more precise estimates occurring after the program's first-year budget requests are approved.
- The procurement process results in cost reductions.
- Modification scope may be restricted.
- Modification costs are padded up to 30 percent to account for risk associated with concurrent production and research and development.
- Air Force estimates tend to be high to preclude the necessity and delay of requesting additional funds.

The GAO study is evidence that accurate modification cost models did not exist at the end of 1987.

In 1990, the Boger and Liao Aircraft Modifications Cost Analysis, funded by the NAVAIRSYSCOM Cost Analysis Division, NAIR-524 [Ref. 17] attempted to develop CERs for aircraft modification programs. The comprehensive, multi-year study was started to assist NAVAIRSYSCOM in accurately estimating aircraft modification program costs, which were

approaching $2 billion annually in DON. The study discussed the current DON policy of pursuing aircraft modification efforts instead of procurement. The study also noted the need for modification cost models due to the increased use of this method to upgrade DON aircraft in the austere funding environment of DOD.

Boger and Liao noted that NAVAIRSYSCOM did not possess an aircraft modification cost estimation model, and this impeded execution of planning studies and COEAs. Both audits of NAVAIRSYSCOM by the DOD Inspector General and existing DON Instructions document the need for this type of model to aid aircraft modification planning and management.

Boger and Liao discussed four factors that affect aircraft modification cost model development:

- Modifications vary in complexity.
- Modifications vary by individual aircraft.
- Various methods and organizations are used to accomplish modifications.
- Organizations that accomplish modifications have different levels of prior experience and facilities.

The Boger and Liao CER effort proved completely unsuccessful, primarily due to the unique character and tailored nature of each modification, and the four factors above [Ref. 17].

The preceding literature review leads to the conclusion that aircraft modification program CERs did not exist as of March 1993, ruling out use of the parametric cost estimation technique. Since engineering cost estimates are

unsuitable for early COEA analyses, this thesis uses the analogous cost estimation method as the principal technique for estimating the P-3 avionics modification costs required for the COEA.

2. New Aircraft Cost Estimation Techniques

RAND Corporation has also been the leader in developing CERs for new aircraft airframes. In 1972, RAND generated a long-range cost estimation planning model that predicted the cost of military airframes [Ref. 18]. The model, using multiple regression analysis, related cost or man-hours to aircraft physical and performance characteristics, essentially aircraft unit weight and speed.

In 1976, RAND produced a further study of airframe CERs for ASD(PA&E) [Ref. 19]. The new model attempted to address existing user concerns with the 1971 model, including lack of additional explanatory variables, individual aircraft classes, and changes in airframe structural materials. The model proved only partially successful. Aircraft unit weight and speed were still the most statistically significant explanatory variables. Of all structural materials examined, only construction involving aluminum provided sufficient information to draw conclusions about the impact of structural changes on cost.

The last study, conducted by RAND in 1987, updated and extended the CERs developed in 1976 [Ref. 20]. Additionally,

the study divided the full estimating sample into subsets representing major aircraft types, and examined the explanatory power of program structure and airframe construction techniques. Unfortunately, the subset most applicable to this thesis, the bomber and transport subset, did not yield a single acceptable CER for any individual or total program cost element. Attempts to incorporate subsets, program structure and airframe construction techniques were considered unsuccessful. The RAND study recommended that estimates be developed by analogy or by using the equation set developed by aggregating data from all aircraft mission types. The study concluded that the most representative equation set still used aircraft empty weight and speed as the designated explanatory variables, repeating the conclusions of the 1972 RAND report [Ref. 18]. The RAND CERs produced by Hess and Romanoff are used in Appendix A to validate the new P-3 cost estimate developed using the analogous method.

C. COST VARIANCE ESTIMATION TECHNIQUES FOR COST ESTIMATES

Cost estimates are future predictions subject to uncertainty and inaccuracies. Once a program's original cost estimate is developed, it changes over time as new information becomes available. A method is needed to quantify these program cost estimate changes, or variances, which are defined as the difference between a weapon system's original and current cost estimates. The original cost estimate can be

adjusted by identifying cost variances which are categorized as cost growth or cost reductions.

For example, assume that costs for a particular program have grown 15% over the original program cost estimate. If the cost variance could have been estimated by some method, the original estimate could have been adjusted as follows: [(Original Cost Estimate) x (Cost Variance/100)] + [Original Cost Estimate] = [Adjusted Cost Estimate].

This thesis uses analyses of DOD SAR data to determine cost variance. This is one approach among many that can be used to determine cost variance.

The DOD SAR measures cost variance using the concept of the baseline. According to Tyson of IDA, one type of baseline, the development baseline, can be defined as:

> ...the estimates of technical, schedule, and cost goals at the time that the program entered full-scale development (FSD). Technical goals...cover the weapon system's performance and technical characteristics... schedule goals...include dates for FSD contract award, initial operating capability (IOC), and the various acquisition milestones. The cost goals include costs for development, production, military construction, and other program costs in both current and constant dollars. Each program has an established base year, typically the FSD year. [Ref. 21]

This thesis, therefore, is primarily interested in SAR cost variance, and how it changes over time with respect to a selected baseline. By quantifying those changes, the data can be used to attempt to improve cost estimate accuracy.

1. Single Program Measures

Management Consulting and Research, Inc. (MCR), a private contractor performing an analysis for ASD(PA&E), formulated a simple cost variance measure in 1981 to quantify DOD acquisition program cost growth [Ref. 22]. The measure, a ratio of the difference between the current estimate (CE) and the development estimate (DE), divided by the DE, was measured in current year dollars. Disadvantages included a lack of adjustment for quantity or inflation.

In 1979, RAND released a study that stressed a different method of quantity adjustment [Ref. 23]. Cost variance, calculated in base year dollars, was measured as a ratio of CE to DE. RAND adjusted quantity back to DE quantity (avoiding the "floating baseline" problem by essentially holding quantity constant) by subtracting the SAR quantity variance from the CE. RAND then normalized the variance along the program's cost-quantity curve, which is an improvement curve that implies a non-linear reduction in unit costs as quantities increase.[3]

In 1989, an IDA report evaluated major system cost and schedule trends and acquisition initiative effectiveness [Ref. 24]. Approach advantages included separation of development

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[3]The cost-quantity curve is synonymous with the "learning" curve, a function defined as follows: Variable cost of the Qth unit = [Variable cost of the first unit] x [(Cumulative Quantity)^ (Learning Index)], where the learning index is negative. Typical learning index numbers range from -0.70 to -0.95.

and production cost growth and a new quantity adjustment method. IDA, believing that SAR variance category data was unreliable, disregarded it entirely. Instead, price-improvement curves were developed independently from SAR annual data for completed program production years. The cost of the originally planned development estimate quantities was calculated using these curves.

In 1991, Bliss of OSD(PA&E/EA&RPD) reported on the analysis of data assembled by RAND in an ongoing study of cost growth [Ref. 25]. The report discussed characteristics and causes of SAR cost growth, validity of SAR cost data, and data normalization techniques for 27 of 107 potential systems that submitted SARs. To reduce the scope of the study, the systems evaluated were the best and the worst performing systems as measured by the RAND-derived aggregate cost growth factor. They were spread over six commodity classes: missiles, combat aircraft, combat vehicles, ships, helicopters, and electronics.

Bliss normalized the data for inflation and quantity, using a normalization procedure developed at RAND. The following results were reported:

- Defense cost growth is more modest than commonly assumed and generally more modest than cost growth experienced in comparable economic sectors, such as that experienced when building large industrial power plants.

- Cost growth from discretionary sources, such as decisions external to program's defined Milestone II baseline, is twice that of growth associated with "estimation error."

These decisions include changes in system capability and acquisition strategy changes.

- Many factors previously cited as sources of cost growth (concurrence, failure to achieve program planned procurement rates, "turbulence", etc.) are not powerful explanatory variables in themselves.

- The most important explanatory variables are program size and commodity class, with size inversely related to cost growth (smaller programs incur greater proportional cost growth than larger programs).

In 1992, Hough of RAND documented pitfalls associated with calculating cost growth using SAR data [Ref. 26]. The RAND note observed that many changes had been made over time to improve the quality of SAR data. Even so, the following notable problems remain:

- Failure of programs to use consistent baselines,

- Exclusion of some significant cost elements,

- Exclusion of special access programs,

- Constantly changing preparation guidelines,

- Inconsistent interpretation of preparation guidelines across programs,

- Unknown and variable funding levels for the program manager's program risk fund,

- Cost sharing in joint programs, and

- Reporting of cost change effects instead of their root causes.

In order to cope with these problems, the cost analyst using SAR data must apply adjustments, realizing that not all effects are correctable.

Two problems that are correctable using accepted analytical approaches are inflation and changes in quantity.

According to Hough, the quantity changes are adjusted to the originally estimated quantity using two methods:

> The simplest method extracts the amount the SAR reports for quantity and adjusts the current estimate accordingly. More sophisticated methods involve an adjustment based on the program's total cost-quantity curve. When quantity has changed frequently and by a large margin, the method used and the care taken to fully capture all costs related to the change can result in strikingly different measures of cost growth for the same program. [Ref. 26]

Hough's note concludes by stating that SAR data is suitable for identifying broad-based trends and temporal patterns across a wide range of programs.

2. Multiple Program Measures

In 1980, IDA examined cost growth for multiple programs over two time intervals, DE to Initial Operational Capability (IOC), and IOC to latest available estimate [Ref. 27]. The approach used by IDA has the following advantage:

- Separation of past and future program growth,
- Adjustment made for inflation, and
- Development and production cost growth was measured separately and in total.

The principle disadvantage of the IDA approach is the lack of a quantity adjustment.

In the IDA report issued in 1989, program aggregation was done differently [Ref. 24]. Program inclusion was dependent upon maturity. Programs having fewer than three years of experience past a particular baseline were not

included. Also, total program cost growth was calculated using a weighted average method based on program size in base year dollars.

In 1992, Drezner of RAND, in work ongoing for the United States Air Force, analyzed weapon system cost growth for 197 major weapon systems reporting in the SAR system as of December 1990 [Ref. 28]. Drezner normalized the data for inflation and quantity effects, and used a weighted average cost growth method to account for program size when aggregating the data. Program maturity effects were accounted for by only including programs three or more years past full scale development start. All cost growth was referenced to and measured from a specific baseline, i.e., cost growth was measured *from development and production* baselines separately.

Drezner's objectives were to quantify the magnitude of the cost growth problem and identify factors affecting cost growth. Drezner discovered that cost estimates were systematically biased towards underestimation, with approximately 20% cost growth experienced at both planning and development baselines, decreasing to 2% at the production baseline. There was no apparent improvement over time; cost growth has fluctuated around 20% since the mid 1960s.

In addition, the following was discovered with respect to factors involving cost growth:

> ...we examined many possible explanatory variables, including macro level development strategies, schedule related factors, and

> management and budget considerations...We found few strong relationships...While program length, program size, maturity, and modification versus new developments are significant correlations, no single factor explains a large portion of the observed variance in cost growth outcomes...there is no "silver bullet" policy response to...cost growth. [Ref. 28]

Drezner concludes by suggesting that any policy solution will be complex, incorporating all aspects of the acquisition process and requiring changes in behavior of all responsible parties. He states that the sum of current DE program baseline cost estimates is $450 billion, and if 20% ($90 billion) could be considered significant, then correcting the problem warrants the effort involved.

In 1993, Drezner of RAND, in work forthcoming for ASD(PA&E), *describes the Defense System* Cost Performance Database (DSCPD) [Ref. 9]. The report's goal is to provide a "living" data base for use by analysts both in and out of government to improve understanding of the weapon system cost growth problem. Limitations and caveats used while creating DSCPD are documented, and the data base is internally consistent. The DSCPD is projected to be updated annually.

D. OPTIMIZATION MODEL

MPAMOD1 is a mixed-integer optimization model [Ref. 29] that is a variant of common production/inventory planning models [Ref. 30]; the major difference is that MPAMOD1 does not incorporate external demand. Instead of external demand,

aircraft procurement and/or modifications are driven in MPAMOD1 by inventory and fleet effectiveness requirements.

MPAMOD1 stems from the "PHOENIX" optimization model used to modernize the U. S. Army's helicopter fleet in the late 1980s [Ref. 11]. The PHOENIX model

> ...captured complex procurement and modernization tasks in an optimization-based decision support system...[that] recognizes yearly operating, maintenance, service-life extension, and new procurement costs while enforcing constraints on fleet age, technology mix, composition, and budgets over a multi-year planning horizon...PHOENIX has been adapted to tactical wheeled vehicles and is under consideration for further applications. [Ref. 11]

The PHOENIX model was tailored for long-range planning, at a high level of detail, for capital equipment procurement, use, repair, and retirement. Individual helicopter programs were optimized in the larger context of their impact on overall Army helicopter fleet effectiveness.

Two Naval Postgraduate School Masters theses, written in 1990 and 1993, applied the methodology of the PHOENIX model to MPA fleet modernization. The first thesis, by Drash, developed a model (referred to as the "Drash model") that is outdated because it does not include the proper mix of current MPA modernization and life extension programs [Ref. 31]. The second thesis, by Osborn, developed a model (referred to as MPAMOD) that implemented all current MPA programs [Ref. 32]. MPAMOD1 incorporates minor modifications to Osborn's MPAMOD.

MPAMOD1 produces output that delineates annual program life cycle costs, program executability within budget

constraints, and preliminary aircraft modification scheduling over a long term program planning horizon. It provides necessary information to optimize P-3 COEA alternatives in the larger context of their impact on overall P-3 fleet effectiveness. In short, MPMOD1 provides planning information required to select the best COEA alternative, and gives a "first cut" answer to solution implementation.

E. CONCLUSIONS

After examining the literature, the following conclusions can be drawn:

- CERs do not exist for aircraft modification programs.
- CERs do not exist for the subset of bomber and transport new production aircraft. The CERs recommended for use involve aggregation of all aircraft mission type data.
- A methodology exists to determine program cost variance using SAR data. Applying the calculated cost variance is one method of improving cost estimate accuracy.
- The COEA's use of a mixed integer optimization model to optimize resource allocation provides information needed to select and implement the best COEA alternative.

These conclusions result in the following effects for this thesis:

- Cost estimates are calculated using the analogous method. The RAND CER equations produced by Hess and Romanoff are used only to validate the cost estimate for the new production P-3.
- The cost variance analysis uses data generated by the author and by the RAND DSCPD.

III. COST ESTIMATES FOR COEA ALTERNATIVES

A. INTRODUCTION

The first COEA alternative's cost estimate, the status quo, is not required because all prior production costs for current fleet P-3s are sunk costs. Operations and Maintenance (O&M) costs for all alternatives are addressed in Chapter V.

All other cost estimates are developed using the analogous method. The analogous cost estimates are less accurate than desired because of limited access to original source cost data. Detailed cost estimate calculations are provided in Appendix A. The estimates are then compared to historical cost data contained in Appendix B to judge estimate validity.

Cost estimates for two P-3 life extension programs are also included. The costs are required for certain COEA scenarios that evaluate P-3 service life extension effects.

B. COST ESTIMATE FOR P-3 ASUW IMPROVEMENT PROGRAM

The P-3 AIP is being rapidly implemented through use of the acquisition concept of "streamlining", defined as follows:

> ...It is the policy of DOD to use commercial and other nondevelopmental items to the maximum extent practicable in procurement of supplies...the policy is designed to promote efficiency in the use of taxpayer resources to procure supplies and provide timely and effective support for the armed forces.[Ref 33]

This concept requires the following key assumptions to be made concerning the modification cost estimate:

- The design uses current off-the-shelf (COTS) non-developmental item (NDI) systems.
- The COTS/NDI systems are all flying or have previously flown.
- No initial RDT&E is required, although follow-on test and evaluation (FOT&E) is needed.
- All hardware initially operates as stand alone systems, with full P-3 software integration deferred for later preplanned product improvement (P3I) efforts.
- The AIP modification is installed in a baseline P-3C Update III aircraft that has a ASQ-212 (CP-2044) Data Processing System (DPS), Global Positioning System (GPS), and ALR-66(V)3 Electronic Support Measures (ESM) System.

These are valid assumptions because the systems that comprise the P-3 AIP are currently flying in specially modified P-3 "Outlaw Hunter" aircraft or on other DOD aircraft. Only minimal software integration is contemplated for the AIP, and no RDT&E is presently funded.

In general, avionics modifications are procured as "kits" and installed in applicable aircraft by commercial contractors or government repair facilities, such as Naval Aviation Depots (NADEPs). Modification "A" kits consist of airframe and installation components. Modification "B" kits include all avionics equipment. For purposes of standardizing the cost estimate summary table, "A" kit costs are placed in the "Airframes/Changes" category and "B" kit costs in the "Electronics/Comm" category. These are arbitrary groupings used for comparison and evaluation purposes only.

1. System Description

The P-3 AIP's new sensor subsystems include an Inverse Synthetic Aperture Radar (ISAR), improved Electronic Surveillance Measures (ESM) with spinning direction finding (DF) antennae, Infrared Detection System (IRDS) improvements, and an electro-optical surveillance system.

TABLE III
P-3 ASUW IMPROVEMENT PROGRAM SUBSYSTEMS

CATEGORY	SUBSYSTEM
SENSORS	- APS-137(V)5 ISAR Radar - ULQ-16(8.0) ESM Mod - ESM Spinning DF Antenna - AAS-36 IRDS Improvement - Electro-Optical System
COMMUNICATIONS	- OTCIXS - TRE - DAMA SATCOM Secure Voice - ICS Modifications
DISPLAYS AND CONTROLS	- (3) CHRDs, (1) PCHRD - (3) PEPs, (2) DEP - Keyboards and Trackballs - Hard Copy Recorder
SURVIVABILITY	- Fuel Tank Foam - Missile Warning and Countermeasures Provisions
CENTRAL PROCESSING SYSTEM	- Minimum Hardware Mods - Minimum Software Mods

New communication subsystems include Officer in Tactical Command Information Exchange System (OTCIXS), Tactical Receive Equipment (TRE), Demand Access Multiple Address (DAMA) capable Satellite Communications (SATCOM) secure voice, and Intercom Communications System (ICS) improvements. Three sets of Color

High Resolution Displays (CHRD) with associated Programmable Entry Panels (PEP) are installed at the Tactical Coordinator (TACCO), Navigation/Communicator (NAVCOMM), and Sensor Station 3 (SS3) stations. A Pilot Color High Resolution Display (PCHRD) and associated Data Entry Panel (DEP) is installed in the cockpit. The P-3 AIP systems are summarized in Table III.

2. Cost Estimate

The P-3 AIP costs are expressed in constant FY 1993 dollars using March 1993 deflators obtained from the Navy Center for Cost Analysis (NCA). The detailed cost estimate methodology (Appendix A) uses an analogous approach to generate modification kit costs. The kit costs are then multiplied by the yearly procured quantity and added to non-recurring engineering (NRE) costs to calculate total program flyaway cost. Support equipment, training equipment, and spares are added to determine program acquisition cost.

Modification kit unit costs remain constant over program life. Omission of the role of learning in this modification program is justified as follows:

- The program's acquisition and contracting strategy requires COTS/NDI subsystems purchased by "piggy-backing" onto existing government contracts. Other government agencies/programs have already reaped the benefits of any subsystem learning.
- Relatively minor airframe and internal cabin modifications are required.
- Appropriate inflation factors have been applied to previously purchased kit items.

The P-3 AIP cost estimate is summarized in Table IV.

TABLE IV
P-3 ASUW IMPROVEMENT PROGRAM COST ESTIMATE
(THOUSANDS OF FY93 DOLLARS)

CATEGORY	TOTAL COST		UNIT COST
Airframe/Changes	146,540		
NRE	35,000		
Engines/Access	0		
Electronics/Comm	327,624		
Armament/Other	0		
Total Flyaway	509,164	509,164	7,488
Ground Support Eq	43,188		
Training Eq/Other	120,306		
Weapon Sys Cost	163,494	672,658	9,892
Initial Spares	76,923		
Procurement Cost	76,923	749,580	11,023
RDT&E	0		
Military Const	0		
Program Acq Cost	0	749,580	11,023

C. NEW PRODUCTION P-3 COST ESTIMATE

The COEA new production aircraft alternative, the P-3 ORION II, is a new airframe based on the existing P-3 design. The program's acquisition strategy is to procure the new aircraft as a reprocurement of an existing design, requiring the following cost estimate assumptions to be made:

- The ORION II is an Acquisition Category 1D program that enters the procurement process at Milestone IV.
- The contract is let sole source to Lockheed to take advantage of existing P-3 tooling and expertise.
- Risk is considered low because all systems are NDI.
- The buy will take advantage of the existing production line from a foreign procurement, but a gap will exist before Navy production begins.

- Because the contract is sole source, competition is maximized at the subvendor level.

1. System Description

The Orion II program meets operational requirements drafted January 1991. Those operational requirements include:

- Range/endurance of 1600 nautical miles/4 hours on station,
- A 5000 pound payload with provisions for future growth,
- Capacity for 120 sonobuoys,
- Weapons upgrades, and
- Inflight refueling.

The ORION II systems are summarized by category in Table V.

TABLE V
ORION II SYSTEMS

CATEGORY	SYSTEM
AIRFRAME	- Increased Zero Fuel Weight and Takeoff Gross Weight - New Engines - Improved Aux Power Unit - Pressurization Improvements - Fuel Tank Foam - Survivability Provisions - Inflight Refueling - Anti-skid and Carbon Brakes
AVIONICS	- Update III Plus Systems - AIP Systems - Digital Magnetic Anomaly Detection (MAD) Sensor - Color Weather Radar - Ring Laser Gyro Inertial - Digital Fuel Quantity
ARMAMENT	- MK-50 Torpedo - Provisions for 120 "A" Size Sonobuoys

2. Cost Estimate

The P-3 ORION II new production aircraft program procures 68 aircraft over a seven year period. All costs are expressed in constant FY93 dollars using the 1993 NCA deflators, but aircraft unit costs do not remain constant over program life. A learning curve of 90% is assumed for this aircraft procurement program based on historical and projected contractor performance[4]. The P-3 ORION II detailed analogous cost estimate is given in Appendix A. The cost estimate is summarized in Table VI.

TABLE VI
P-3 ORION II COST ESTIMATE
(THOUSANDS OF FY93 DOLLARS)

CATEGORY	TOTAL COST		UNIT COST
Airframe/Changes	3,218,700		
NRE	326,700		
Engines/Access	527,900		
Electronics/Comm	1,226,800		
Armament/Other	26,200		
Total Flyaway	5,326,300	5,326,300	78,328
Ground Support Eq	463,100		
Training Eq/Other	695,200		
Weapon Sys Cost	1,158,300	6,484,600	95,361
Initial Spares	375,500		
Procurement Cost	375,500	6,860,100	100,884
RDT&E	195,600		
Military Const	0		
Program Acq Cost	195,600	7,055,700	103,760

[4]Variable cost of the Qth unit = [Variable cost of the first unit] x [(Cumulative Quantity Q)^ (-0.90)]

D. COST ESTIMATE FOR P-3 UPDATE IV

The P-3 Update IV program was conceived and executed in the mid-1980s to aid P-3 efforts against enemy fifth generation submarines. Primarily an Antisubmarine Warfare (ASW) improvement program, it was cancelled in 1992 as the submarine threat abated. It is considered in this thesis because it is more than three times the size of the P-3 AIP modification program and therefore provides a more representative program than that program for use when comparing the cost effectiveness of aircraft modification programs to new aircraft procurement programs. The procurement and modification programs are assumed to yield different service lives, with the aircraft modification program yielding the shorter service life. The system description is provided in Appendix A.

The P-3 Update IV program modifies 68 aircraft over a seven year period by incorporating a modification kit. All costs are expressed in constant FY93 dollars using 1993 NCA deflators. Modification kit unit costs do not remain constant over program life. A 90% learning curve is assumed based on the following:

- program size,
- extensive airframe and internal cabin modifications, and
- new acoustic equipment unique to Update IV.

The P-3 Update IV detailed analogous cost estimate is available in Appendix A. The cost estimate is summarized in Table VII.

TABLE VII
P-3 UPDATE IV COST (P-3 UIV) ESTIMATE
(THOUSANDS OF FY93 DOLLARS)

CATEGORY	TOTAL COST		UNIT COST
Airframe/Changes	477,156		
NRE	147,000		
Engines/Access	0		
Electronics/Comm	858,466		
Armament/Other	0		
Total Flyaway	1,482,622	1,482,622	21,803
GSE/Trng Eq/Other	585,630		
Weapon Sys Cost	585,630	2,068,252	30,415
Initial Spares	223,000		
Procurement Cost	223,000	2,291,252	33,694
RDT&E	319,000		
Military Const	0		
Program Acq Cost	319,000	2,610,252	38,386

E. COST ESTIMATES FOR P-3 LIFE EXTENSION PROGRAMS

Two P-3 life extension programs are examined for the P-3 COEA, the Sustained Readiness Program (SRP) and the Service Life Extension Program (SLEP). The SRP's purpose is:

> ...to preemptively replace airframe components and systems identified as having potential for significant impact on future aircraft availability due to excessive time to repair, obsolescence, component manufacturing lead time or cost impact. [Ref. 34]

The SLEP is designed to extend P-3 fatigue life by replacing fatigue critical components. Whereas the goal of the SRP is to capture 100% of aircraft fatigue life, the goal of the SLEP is

to extend an aircraft's fatigue life beyond 100%. The model currently retires P-3s without life extensions at 30 years. SRP and SLEP modified P-3s are retired 8 and 10 years after the modifications are installed, respectively.

The estimates were developed using information supplied by PMA-290. All costs are in constant FY93 dollars calculated by using NCA deflators.

1. THE P-3 SUSTAINED READINESS PROGRAM

The P-3 SRP is an airframe and selective equipment replacement program to renovate 193 of the 247 existing P-3C aircraft, or 78% of the fleet. On the basis of historical data, the average life extension realized from capturing 100% of aircraft fatigue life is eight years. The P-3 SRP cost estimate is summarized in Table VIII.

TABLE VIII
P-3 SUSTAINED READINESS PROGRAM COST ESTIMATE
(THOUSANDS OF FY93 DOLLARS)

CATEGORY	TOTAL COST		UNIT COST
Airframe/Changes	1,367,136		
NRE	6,812		
Engines/Access	0		
Electronics/Comm	0		
Armament/Other	0		
Total Flyaway	1,373,948	1,373,948	7,119
Support/Trng Eq	42,989		
Weapon Sys Cost	42,989	1,416,937	7,342
Initial Spares	1,199		
Procurement Cost	1,199	1,418,136	7,348
RDT&E	0		
Military Const	0		
Program Acq Cost	0	1,418,136	7,348

2. THE P-3 SERVICE LIFE EXTENSION PROGRAM

The P-3 SLEP is still in the preliminary stages of program formulation. Preliminary discussions with program officials [Ref. 35] have indicated the SLEP target unit cost goal to be $3.5 million (FY93). The SLEP modification extends aircraft service life ten years.

F. COST ESTIMATE VALIDATION

The cost estimates for the three COEA alternatives are now compared, for validation purposes, to historical cost data taken from Appendix B. The method used involves comparing unit flyaway costs and using ratio analysis of various cost categories (ratios of total support, spares, and RDT&E costs to total flyaway costs). A summary of the comparison data, obtained from Appendix B and Chapter III, is presented in Table IX.

TABLE IX
P-3 HISTORICAL AND CURRENT COST ESTIMATE COMPARISON
(MILLIONS OF FY93 DOLLARS)

COST ESTIMATE/ COST OR RATIO	P-3 UIII 1984 SAR	P-3 UIII 1989 SAR	P-7A	P-11	P-3 AIP	P-3 UIV	ORION II
TOTAL FLYAWAY COST	3523.6	1236.6	5207.8	5830.3	509.2	1482.6	5326.3
QUANTITY	80	32	125	68	68	68	68
UNIT FLYAWAY COST	44.1	38.6	41.7	85.7	7.5	21.8	78.3
SUPPORT RATIO	29%	33%	13%	20%	32%	39%	22%
SPARES RATIO	2%	2%	12%	8%	15%	15%	7%
RDT&E RATIO	11%	6%	19%	15%	-	22%	4%

First, unit flyaway costs for the ORION II COEA alternative and the four historical aircraft are compared. The ORION II's unit flyaway cost is much greater than the two early P-3C UIIIs and the later P-7 aircraft, and more closely resembles the P-11 estimate generated from Hess and Romanoff's 1987 CER data, discussed in detail in Appendix B. This can be attributed to the numerous structural changes envisioned for the ORION II airframe, which is different from previous patrol aircraft designs. It is more similar to a new aircraft than to a previous or existing weapon system, and the data reinforces this fact. The ORION II unit flyaway cost is reasonable in this light. Second, ratios for total support equipment, spares, and RDT&E costs as a percentage of total program flyaway cost are compared. The P-3 AIP is examined initially, followed by the ORION II and Update IV programs.

The P-3 AIP support ratio is reasonable, but the spares ratio of 15% seems high. The preponderance of new systems in the AIP design and their unique sparing needs explains this anomaly. The historical data is weighted towards lower spare ratio percentages due to system commonality with previous designs, requiring fewer unique sparing requirements. The simple answer is that if the spare parts do not already exist in the supply system in quantity, as was the case in earlier P-3 modification programs, the program must buy them.

The Update IV support ratio (39%) and spares ratio (15%) also seem higher than normal. This is explained by the

preponderance of new advanced ASW systems, and the need to support and spare them accordingly.

When compared to the historical data in Table IX for similar systems, the ORION II's support (22%), spares (7%) and RDT&E (4%) ratios are very similar, confirming the validity of these costs for the cost estimate. Initial spares procurement is greater than that of previous Update III programs, but less than the P-7A program. This is explained by the greater commonality of ORION II systems with the current P-3 fleet, comprised mainly of P-3C UIIIs. This also explains ORION II's low RDT&E ratio.

In conclusion, the ORION II flyaway cost, and the COEA alternatives and the P-3C Update IV support, spares, and RDT&E cost estimate ratios *seem reasonable* in light of program characteristics. The cost estimates pass validity checks.

G. CONCLUSIONS

Cost estimates for the COEA alternatives and the P-3C Update IV have been generated from detailed analogous cost estimates given in Appendix A. They have been compared to costs for similar historical systems and are reasonable.

Recognizing that cost estimates are subject to uncertainties, a cost variance analysis using data obtained from SAR documents is conducted next. The analysis results are applied to the current cost estimates to improve their accuracy.

IV. COST VARIANCE ANALYSIS

A. INTRODUCTION

After initial cost estimates are generated and their validity checked by comparison to previous historical cost estimates, some effort should be made to improve their accuracy. This is known as cost variance analysis. The SAR-based cost variance analysis is one of many such methods that can be used.

A cost variance that is either cost growth or cost reduction is estimated from actual historical performance for similar acquisition programs. The data to estimate this variance is found in DOD SAR documents. It is applied to the original cost estimate as follows:

[Adjusted Cost Estimate] = [(Original Estimate) x (1 + Variance)].

This chapter first defines cost variance. It then outlines an author-developed five step method similar to the RAND method [Ref. 28] for calculating cost variance. These calculations are then made, followed by a validation of the results, and chapter summary.

B. THE DEFINITION OF COST VARIANCE

The cost estimate sensitivity analysis is based on the concept of "cost variance". Otegui defines cost variance as:

> ...the difference in cost between the original and current estimate of a given weapon system...it carries no *a priori* implication of inefficiency even when the variance is an increase: the variance may well be--and in fact, often is --the result of efficiency neutral events or conditions...it can result from changes in events, procedures, and processes in weapon system procurement. [Ref. 36]

Cost variances can be either cost growth or cost reduction. The SAR estimates cost variance by appropriation and category [Ref. 10]. The SAR categories, in order of application, are depicted in Table X.

TABLE X
SAR COST VARIANCE CATEGORIES

CATEGORY	DESCRIPTION
Economic	Change due to economic price level changes.
Quantity	Change in the number of end units of equipment.
Schedule	Change in procurement or delivery schedule.
Engineering	Alteration to functional system characteristics after their establishment.
Estimating	Change due to correction of a baseline cost estimate error or assumption.
Other	Change due to natural disaster, work stoppage, and other unforeseen events.
Support	Change for training and support equipment, data, and initial spares.

This thesis disregards the cost variance in the Economic and Quantity categories and emphasizes that associated with the Schedule, Engineering, Estimating, Support, and Other categories. Justification for the exclusion of the first two categories is as follows:

- Inflation is notoriously hard to predict. While its existence and effect on program cost is known (inflation causes cost growth), the magnitude of the cost growth is uncertain.
- Quantity changes are unpredictable. Over the average program's ten year path to production, both the magnitude and effect of those changes are uncertain.
- Program management decisions do not influence inflation and quantity changes per se. The program manager simply accepts the DOD mandated policy and works with it.

The SAR-based sensitivity analysis attempts to improve the original cost estimate's accuracy. Subsequent examples show analyses that remove the unpredictable effects of inflation and quantity, and estimate the cost variances associated with the Schedule, Engineering, Estimating, Support, and Other categories. This particular approach, as subsequent examples show, can lead to more accurate cost variances and more accurate cost estimates.

Since the dawn of the republic, analysts and managers have consistently underestimated the cost of future weapon systems. The earliest documented case involved congressional attempts to provide the Navy with six frigates in 1794 [Ref. 36]. The subsequent buy was plagued with schedule delays, cost growth and mismanagement, due primarily to the political requirement

to build the vessels in six different shipyards in six different states. In the subsequent 200 years, very little has changed. As an Air Force sponsored RAND report that normalized data for inflation and quantity effects states:

> ...As an estimating goal, we might hope that, on average, our cost estimates are unbiased with a mean cost growth of zero, and that accuracy improves over time as a function of improved information...our results indicate that cost estimates are in fact systematically biased toward underestimation: cost growth is about 20% at both the planning (Milestone I) and development (Milestone II) baselines, falling to about 2% at the production (Milestone IIIa) baseline...there is a very high variance around those averages...the data is highly skewed towards cost growth...and distribution does not improve significantly over time as better quality information becomes available. [Ref. 28]

Cost growth seems to be the program norm due to underestimated costs in the five categories mentioned above. This point is further reinforced by Bliss of ASD(PA&E), who discovered that of the cost growth measured in the above categories, more than 66% results from discretionary decisions made by program management subsequent to full-scale development [Ref. 25].

The ultimate goal of the sensitivity analysis is accurate cost estimates that allow objective comparisons of competing P-3 COEA alternatives. The thesis disregards the cost variances associated with inflation and quantity changes due to their inherent unpredictability. In the COEA, all cost comparisons are made in base year (FY 1993) dollars, and each COEA alternative is evaluated holding system quantities constant. This minimizes the above effects.

The methodology proposed uses data extracted from SAR documents and the RAND Defense Systems Cost Performance Data Base (DSCPD), currently under development for ASD(PA&E) [Ref. 9]. First, the methodology for obtaining both data sets is described, and differences between the author's and the RAND approach are noted. Second, the data are presented in tabular form. Finally, the author's and RAND values are compared and predicted historical cost variance for the COEA is determined.

C. METHODOLOGY

The methodology for obtaining the predicted historical cost variance is as follows:

- Tailor the SAR data to fit acquisition program needs,
- Determine the program baseline,
- Normalize the data for inflation effects,
- Normalize the data for quantity effects, and
- Use a weighted average method to aggregate programs.

Specific problems encountered and techniques used in the five major methodology areas are discussed below.

1. Tailoring the Data Base

A list of 225 current and former programs that required SARs was provided by the Office of the Undersecretary of Defense (Acquisition)/Acquisition Policy and Program Integration/Program Management (OUSD(A/AP&PI/PM)) [Ref. 37]. From the list, 15 programs were selected that were most like the COEA alternatives. The subset evaluated included all

large, non-fighter/attack aircraft, both new production and modified. The only eligible program not included was the C-5A, which never reported in base year dollars, thereby excluding its use. Drezner, of RAND, found 15 other early programs in the SAR data having this problem [Ref. 28].

The diverse Bomber/Transport/Non-Strike aircraft subset is detailed in Table XII. The subset includes ten Air Force and five Navy aircraft. Of the 15 aircraft, eight are new production aircraft and seven are aircraft modification programs. Program SAR reporting start years range from 1968 to 1991, with seven programs reporting before 1980 and eight after. Although a small data set, this subset of programs is representative for the COEA.

2. Determining the Baseline

There can be three different baseline estimates (BE) for each program; the Planning Estimate (PE), the Development Estimate (DE), and the Production Estimate (PdE), with cost variance measured from each. Drezner, of RAND, measured cost variance from each baseline separately by subtracting the BE from the current estimate (CE). This is done because aggregating programs with different baselines blurs fundamental distinctions relating to program maturity and information availability [Ref. 28].

The author's approach is different in that programs with different baselines are combined. Four of the eleven

programs in Table XII have production baselines versus development baselines. It should be noted that these particular programs never had development baselines, only production baselines; they entered the acquisition process at a sufficient level of maturity (Milestone IIIa) to omit the development phase entirely. Since the production baselines in question include all the associated program cost variance, and because they are modification programs representative of one of the three COEA alternatives evaluated, they are included to preclude the already nominal data base from growing smaller.

3. Normalizing for Inflation Effects

The first correction to the measured cost variance involves normalizing for inflation effects. This is accomplished by making all calculations in base year dollars.

4. Normalizing for Quantity Effects

The second correction required involves normalizing the data for quantity effects. The author's approach, described in Hough [Ref. 26], involves adjusting procurement costs by the SAR "Quantity" (Q) variance category amount. The correction, as depicted in Table XI, should capture approximately 75% of all quantity effects [Ref. 38]. The remaining 25% of effects are not captured because not all cost variances due to quantity changes are reported under the "quantity" category. According to DODI 5000.2-M:

> All quantity changes will be calculated using the baseline cost-quantity relationship in effect (PE, DE,

> or PdE)... The difference between the cost of the quantity change based on the baseline cost-quantity relationship and the cost based on the CE cost-quantity relationship will be assigned to schedule, engineering, and estimating categories, as appropriate. [Ref. 10].

The primary reason to recommend the author's approach is speed and ease of use. At this early point in program life, it is accurate enough for COEA purposes.

TABLE XI
DATA ADJUSTMENT FOR QUANTITY VARIANCE

Type of Quantity Change	Normalizing to Baseline Quantity
Increase	(CE - Q)/BE
Decrease	(CE + Q)/BE

With the arrival of the annually updated RAND DSCPD, another potential source of cost variance information is available to cost growth analysts [Ref. 9]. One primary difference between the DSCPD cost variance information and that previously described is the quantity normalization method. RAND uses a method that captures more of the quantity effect. According to Hough:

> ...The method first requires the determination of all reported quantity variance (that is, the dollar amount reported under the "quantity" variance category, *as well as all dollar amounts reported in the other variance categories but identified in the [SAR] narrative as quantity-related.* A *net* procurement variance is then calculated by subtracting the quantity-related variance from the total procurement cost variance. The net procurement variance is then normalized to either the baseline or currently approved quantity using a cost-quantity curve.

> Normalization of the net procurement variance assumes that this residual, which is not explicitly attributed to quantity change in the SAR, is, nevertheless, implicitly influenced by a change in quantity. [Ref. 26]

For COEA purposes, if working with the raw data contained in the SAR, the author's method is preferred. If the RAND DSCPD is available, its use is encouraged because more accurate results are obtained. This is documented in Hough [Ref. 26], who conducted a comparison of the author's and RAND's techniques.

5. Weighted Average Aggregation

Total subset cost growth, after all individual program cost growths are calculated, is derived by calculating a cost growth average weighted by program dollar size. This is important, because, as noted by Bliss in Chapter II, program size and cost growth are inversely related [Ref. 25].

D. TABULAR DATA

Table XII depicts the data collected from the SARs provided by OUSD(A/AP&PI/PM) and found in the RAND DSCPD. Two weighted average cost growth factors are delineated. The first, using the RAND DSCPD, is 11% (see WT AVG CGR/R). The second, from the author's work, is 6% (see WT AVG CGR/T).

E. THE COEA HISTORICAL COST VARIANCE

Before determining which cost growth factor to use, it is worth noting that the overall cost growth for programs of this

type is much less than the average 33% reported by Bliss [Ref. 25] and the average 20% measured from the DE reported by Drezner [Ref. 28]. This can be attributed to a high level of maturity and low overall risk for this type of program compared to the "average" program.

TABLE XII
SAR COST VARIANCE DATA

Program Type/Svc/Mod	Start Year	Base-line	Qty Chng	CGF RAND	FY93$M	WT AVG CGR/R	CGF Thes	FY93$M	WT AVG CGR/Th
B-1A/AF	1968	DE	-	1.17	37236	0.25	1.17	37205	0.24
B-1B/AF/M	1985	DE	0	1.00	34279	0.20	1.00	36313	0.20
B-52/AF/M	1981	PdE	-	0.96	2572	0.01	0.97	2597	0.01
C-5B/AF/M	1984	PdE	0	0.76	10738	0.05	0.76	11710	0.05
C-17/AF	1985	PE	-	1.34	32679	0.25	1.23	34543	0.24
E-2C/N/M	1972	DE	+	1.81	2099	0.02	1.47	6984	0.06
E-3A/AF	1974	DE	-	1.37	12797	0.10	1.26	8016	0.06
E-3A/AF/M	1973	DE	+	1.02	656	0.00	1.02	653	0.00
E-4/AF	1976	DE	-	1.61	1247	0.01	1.54	1351	0.01
E-6/N	1985	DE	+	1.00	2438	0.01	1.05	2461	0.01
KC-10A/AF	1979	PdE	-	1.01	6499	0.04	1.01	6785	0.04
KC-135R/AF/M	1981	PdE	+	0.81	8733	0.04	0.84	9039	0.04
P-3C UIII/N/M	1983	DE	-	0.83	4755	0.02	0.76	4998	0.02
P-7A/N	1991	DE	-	0.97	7489	0.04	0.73	7493	0.03
S-3A/N	1969	DE	-	1.06	10105	0.06	1.04	9312	0.05
					174322	1.11		179460	1.06

The majority of these aircraft were based on commercial designs and modifications of previous aircraft. They used relatively non-exotic technology and materials, significantly reducing program uncertainty. Finally, all three sets of data were normalized for inflation and quantity effects.

The COEA historical cost variance used is the RAND figure of 11%. The RAND method, since it captures more of the quantity effects as opposed to the author's, provides larger quantity adjustments and larger cost-growth factors when quantities are decreasing. Since it is more representative of actual past program performance, it is the cost growth factor of choice.

F. SUMMARY

After a cost estimate is made, some effort should be made to improve estimate accuracy. Historically, program cost estimates have been less than actual program costs, leading to cost growth. An author-developed five step method for determining historical cost growth is as follows:

- Tailor the data base for the particular COEA programs,
- Determine the program baseline,
- Normalize the data for inflation,
- Normalize the data for quantity, and
- Use weighted average program aggregation.

After performing the five step method for this thesis, two COEA historical cost growth variances were calculated. Because the RAND method is more representative of past program performance, its estimate of 11% cost growth is used in this thesis. The cost variance does not take into account the effects of inflation and changes in quantity.

V. OPTIMIZATION MODEL DESCRIPTION

In this chapter, MPAMOD1, the analytical tool for implementing the P-3 COEA alternatives, and its assumptions are described briefly. Next, a list of differences between MPAMOD1 and MPAMOD and a description of required model input and output data are presented.

A. DESCRIPTION

MPAMOD1 minimizes life cycle cost (LCC) over a long-term planning horizon for each of the three COEA alternatives while determining schedules for modification or new aircraft procurement. Inventory flow balance constraints allow for any combination of new production, avionics modification, service life extension via SRP and SLEP, aging and aircraft retirement, depending on the scenario under consideration. The planning horizon is defined as 1993 to 20 years after alternative initial operational capability (IOC)[5]. Cost minimization is restricted, however, since the model is subject to the following budget, physical, and effectiveness constraints:

- Annual budget limits,

[5]IOC is defined as the year the eighth aircraft modification or eighth new production aircraft enters the fleet inventory.

- Annual procurement quantities for new aircraft, avionics modifications, and SRP and SLEP service life extension programs,
- Minimum and maximum inventory levels by year,
- Minimum MOE by year and mission area, and
- Minimum average P-3 fleet life remaining goals.

Some constraints, such as annual budget limits, procurement quantities, and inventory levels, can be very rigid or very loose. For example, the annual new aircraft procurement rate can be specified, or minimum and maximum procurement rates can be specified and the model will determine the number of new aircraft to procure.

The 251 aircraft that comprise the existing P-3 inventory are divided into 95 cohort groups of aircraft with similar characteristics to restrict model size and solution time. For each year of the planning horizon the model decides whether these existing aircraft remain in inventory unmodified, are modified, or are retired.

Each COEA scenario is formulated as a mixed-integer network flow model with side constraints where aircraft are moved over time in yearly increments [Ref. 32]. MPAMOD1 is executed in the General Algebraic Modeling System (GAMS) [Ref. 39]. Although GAMS can be interfaced with many different commercially available solvers, the one selected for use is the X-System solver [Ref. 40]. This solver has handled similar models in the past, such as the PHOENIX, Drash, and Osborn models. MPAMOD1 differs from Osborn's MPAMOD as follows:

- MPAMOD1 revises MPAMOD's cohort groups to allow for differentiation between active and reserve P-3C aircraft and P-3C Update II and Update III versions.
- MPAMOD1 incorporates the P-3 annual Phased Depot Maintenance (PDM) program instead of the Standard Depot Level Maintenance (SDLM) program.
- Annual Operations and Maintenance (O&M) and Phased Depot Maintenance (PDM) costs are calculated for the program's out years.
- MPAMOD1 considers aircraft age and life extension modification programs when calculating O&M costs. Newer aircraft and aircraft receiving SRP and SLEP modifications accrue lower O&M costs.

B. IMPLEMENTATION

1. Input Data Required

A typical model scenario covers a planning horizon consisting of the first year of program preprocurement cost to 20 years after IOC. Any mix of new production aircraft, avionics modification, and SRP or SLEP service life extension programs can be active during the model run.

Other data required for model execution include annual budget limits for each active program and program annual production rates. Total P-3 fleet aircraft inventory goals and minimum average fleet life remaining goals are also set. Aircraft MOEs are obtained from the NAVAIRSYSCOM Warfare Analysis Division, NAIR-526 [Ref. 8], and Chapter III cost estimates provide unit and preproduction cost data for each program. Annual Operations and Maintenance (O&M) and Phased Depot Maintenance (PDM) costs are calculated using information

supplied by the NAVAIRSYSCOM P-3 APML, NAIR-41032 [Ref. 41].

Aircraft loss through attrition is not considered in the model. MPA attrition historically is very low compared to other naval aircraft communities, and its exclusion should not affect MPAMOD1 results. Detailed descriptions of model required input data follow.

a. Cohort Groups

Aircraft are divided into cohort groups using October 1992 structural appraisal of fatigue effects (SAFE) data supplied by the NAVAIRSYSCOM Structures Branch, NAIR-5302 [Ref. 42]. Groupings are based on aircraft age, fatigue life remaining, current avionics fit (either P-3C Update II or Update III), and active or reserve fleet status.

The retirement ages for each individual aircraft are set in the cohort groups based on fatigue rate (annual rate of fatigue life use) and service life extension modification program status. An unmodified P-3 is retired at 30 years; the SRP modification adds 8 years to service life and the SLEP modification adds an additional 10 years.

b. Annual Budget Limits and Production Rates

Annual budget limits are specified in constant FY 1993 dollars. Using unit and preproduction (P) costs generated in Chapter III cost estimates, budgets are calculated that allowed the model to purchase the required quantity streams of modifications and new aircraft (Table XIII).

The AIP annual budget allowed for one time preproduction costs of $35 million and unit costs of $10.5 million, calculated from data contained in Table IV, Chapter III (Calculated as follows in millions: Program Acquisition Cost of $749.6 - NRE of $35 = $714.6; $714.6/68 units = $10.5 million). There is no production lag time; kits are bought and installed in the same fiscal year.

TABLE XIII
BUDGET QUANTITY STREAMS

FY/ PGM	93	94	95	96	97	98	99	00	01	02	03	04-12
AIP	P	13	13	20	20	2						
NEW A/C	P	P	P	6	12	12	12	12	12	2		
SRP		P/2	9	11	10	6	9	15	15	15	15	15
SLEP						P	12	12	12	12	12	12

For the new aircraft, ORION II, the production line opens in FY 1996. The budget permits three years of preproduction costs that are calculated from ORION II NRE and RDT&E costs (in millions: FY 1993-$163, FY 1994-$228, FY 1995-$132). Subtracting these costs from program acquisition costs found in Table VI, Chapter III, yields a budgeted unit cost of $96 million. A three year production lag is built in. For example, aircraft purchased in FY 1996 reach the fleet in FY 1999.

The SRP budget line is calculated as follows: first, preproduction costs of $6.8 million are budgeted in FY 1994; second, unit costs of $7.3 million are calculated from data contained in Table VIII, Chapter III, by subtracting NRE costs from program acquisition costs and dividing by 193 kits. There is a two year production lag built in; aircraft SRP modification kits purchased in FY 1994 are installed in FY 1996.

The SLEP program's budget accounts for $90 million of preproduction costs in FY 1998. Unit costs of $3.5 million were supplied by the P-3 Program Manager, PMA-290. There is no production lag time involved with the SLEP program.

c. Inventory Goals

Navy P-3C fleet inventory goals are set at a minimum of 251 aircraft and a maximum of 275 aircraft. The 251 aircraft lower limit represents the number of P-3C aircraft currently in the fleet.

d. P-3C Average Fleet Life Remaining Goals

Average fleet life remaining goals must be set so that the model modernizes the fleet through purchase of new aircraft and/or incorporation of SRP and SLEP life extension programs. Average fleet life goals are set at 22 years in 1993, and decline to 15 years of average fleet life remaining in year 2012.

e. Measures of Effectiveness

MOEs are obtained from the NAVAIRSYSCOM Warfare Analysis Division, NAIR-526 [Ref. 8]. The AIP modified aircraft and the new production ORION II aircraft are three times more effective at performing the ASUW mission than a baseline P-3C, based on detection ranges and amount of area covered. The MOEs are entered on a scale from 0 to 1 where 1 is the best. Therefore, a baseline P-3C has an ASUW MOE of 0.3, an AIP modified P-3C has an ASUW MOE of 0.9, and a new production ORION II has an ASUW MOE of 1.0.

f. O&M and PDM Budget and Costs

The O&M and PDM budget is calculated using data supplied by the NAVAIRSYSCOM P-3 APML, NAIR-41032 [Ref. 40]. O&M costs are $1,909 per flight hour (FH), and are detailed as follows (FY 1993 dollars): Fuel and Oil - $728/FH, Maintenance Man Hours - $306/FH, Aviation Depot Level Repair Costs - $550/FH, and Consumables - $325/FH. Annual O&M costs are $1.26 million per aircraft for a baseline P-3C with between 16 and 25 years of service life. PDM costs are $151,000 per aircraft per year. This provides sufficient funds to send one quarter of the aircraft through the PDM program every year.

O&M costs are calculated using aircraft age and status as inputs. An older aircraft costs more to maintain than a newer aircraft. Aircraft that have been modified by the

SRP or SLEP programs also cost less to maintain than comparable unmodified aircraft.

2. Output Data Generated

MPAMOD1's objective is to minimize a scenario's total LCCs through optimum implementation of modernization programs and/or procurement over the model's planning horizon. The model also provides an aircraft modification induction schedule and shows where small increases of funding over budgeted amounts in certain years can result in significant downstream operational gains. This data is significant for program managers because it can support plans calling for increased program resources. The model generates various reports to allow analysis of the subsequent output, including:

- Annual aircraft inventory level by program type,
- Annual total costs by program type,
- Annual average fleet life remaining,
- Annual average ASUW fleet effectiveness ratings,
- Projected out year inventory levels and costs, and
- Annual program specific budgets.

The output data for the nine specific scenarios are now examined. The following chapter details the results.

VI. COEA RESULTS

In this chapter, a detailed summary and discussion of the model's output data are presented by scenario. Cost effectiveness of modified aircraft versus new production aircraft are compared, assuming that the modified aircraft has a shorter service life.

A. DETAILED DATA SUMMARY

Nine separate scenarios are run to evaluate the three COEA alternatives and determine the service life extension program's effects. The scenarios are detailed in Table XIV.

TABLE XIV
MPAMOD1 COEA SCENARIO DESCRIPTIONS

SCENARIO	DESCRIPTION
1	Status Quo (SQ)
2	SQ + ASUW Improvement Program (AIP)
3	SQ + AIP + (AIP x 11% Cost Growth)
4	SQ + New Aircraft (ORION II)
5	SQ + ORION II + (ORION II x 11% Cost Growth)
6	SQ + Sustained Readiness Program (SRP)
7	SQ + AIP + SRP
8	SQ + SRP + Service Life Extension Program (SLEP)
9	SQ + AIP + SRP + SLEP

The scenarios are consistent with the general procedures for COEAs found in DODI 5000.2-M [Ref. 10]. They are the

feasible scenarios envisioned for the P-3 community during the 20 year planning horizon of the model, given the budgetary considerations previously detailed in Chapter I. One of the alternatives, Scenario 1, represents the status quo. Addition of the AIP (Scenario 2) results in an improved version of the current program. Scenario 4 is a "separate alternative" (the new production aircraft alternative) whose costs and benefits can be measured against the previous two scenarios to determine if significant advantages are gained through its implementation. The other scenarios allow for service life extension program and historical cost variance effects to be examined.

The thesis scope limits the options that can be examined to those listed above. For the COEA to be truly effective, other air options previously mentioned, such as UAVs and satellite based systems, should be investigated.

The data from the nine COEA scenarios is summarized in Table XV, with subsequent explanations of data categories.

TABLE XV
COEA SCENARIO DATA

SCENARIO/ CATEGORY	1	2	3	4	5	6	7	8	9
# OF A/C									
10 YEARS	193	193	193	235	229	238	238	251	240
20 YEARS	62	62	62	130	120	211	211	249	237
LIFE REM									
10 YEARS	8.02	8.02	8.02	15.4	14.43	9.65	9.65	10.47	9.65
20 YEARS	3.82	3.82	3.82	16.9	15.9	7.41	7.41	8.84	8.37
ASUW MOES									
10 YEARS	0.3	0.51	0.49	0.43	0.41	0.3	0.47	0.3	0.47
20 YEARS	0.25	0.45	0.45	0.59	0.56	0.25	0.41	0.25	0.39
ASUW MOE /20 YRS	15.5	27.9	27.9	76.7	67.2	52.8	86.5	62.3	92.4
LCCs/$MIL									
ANN $$	5064	5778	5783	12912	12503	7937	8650	8590	9018
OUT YR $$	0	165	165	942	854	1174	539	1530	624
TOTAL $$	5064	5943	5948	13854	13357	9111	9189	10120	9642
TOT A/C YRS	3558	3672	3672	5095	4905	5595	5149	6100	5309
A/C FLT HRS/YR	660	660	660	660	660	660	660	660	660
TOT INV FH (MIL)	2.35	2.42	2.42	3.36	3.24	3.69	3.40	4.03	3.50
AVG LCC/ FH ($000)	2156	2452	2454	4120	4126	2467	2704	2514	2752
MOE/LCC RAT x 100	0.72	1.14	1.14	1.86	1.63	2.34	3.20	2.48	3.36
COST RAT		14%	14%	91%	91%	14%	25%	17%	28%
AVG 20 YR MOE RAT		80%	80%	136%	124%	0%	64%	0%	56%
NET TOT MOE		12.4	12.4	61.2	51.7	37.25	71.01	46.75	76.93

The data categories for Table XV are as follows:

- # OF A/C - The number of aircraft remaining in the P-3 fleet at the 10 and 20 year marks, respectively.
- LIFE REM - The average life remaining per aircraft at the 10 and 20 year marks, respectively.
- ASUW MOES - The average ASUW MOE per aircraft at the 10 and 20 year marks, respectively. It is measured on a scale from 0.1 to 1.0, where 1.0 is the best.
- ASUW MOE/20 YRS - The total ASUW MOE is calculated as follows: average ASUW MOE at 20 years x number of aircraft remaining at 20 years. It is a measure of total aircraft inventory and favors scenarios that have increased aircraft totals.
- ANN $$ - Annual LCCs in millions of FY93 dollars summed over the model's 20 year planning horizon.
- OUT YR $$ - O&M and PDM costs in millions of FY93 dollars in the years between the end of the model's 20 year planning horizon and IOC.
- TOTAL $$ - The sum of annual and out year costs.
- TOT A/C YRS - The total number of aircraft inventory years calculated by adding the number of scenario aircraft remaining in the inventory each year.
- A/C FLT HRS/YR - The number of flight hours each aircraft flies in one year.
- TOT INV FL HRS (MIL) - The total projected fleet flight hours flown in the particular scenario, calculated by multiplying the total number of aircraft inventory years by 660 flight hours per year.
- AVG LCC/FH ($000) - The average LCCs of the entire P-3 fleet in thousands of FY93 dollars per flight hour flown. The scenario time horizon extends from 1993 to 20 years after program IOC. It is calculated by dividing total costs by total inventory flight hours.
- MOE/LCC RAT x 100 - The ratio of total ASUW MOE at 20 years to AVG LCC/FH multiplied by 100. It is an indication of cost versus effectiveness.
- COST RAT - The ratio of AVG LCC/FH to the status quo's (Scenario 1) AVG LCC/FH minus 1, expressed as a percent.

It is an indication of the increase in cost over the status quo.

- AVG 20 YR MOE RAT - The ratio of average MOE at the 20 year mark to the status quo's, minus 1, expressed as a percent. It is an indication of the increase in effectiveness over the status quo.

- NET TOT MOE - The scenario's total ASUW MOE at 20 years minus the status quo's total MOE. It is a measure of both remaining inventory levels and the ASUW effectiveness of those inventories.

B. DISCUSSION OF OUTPUT DATA

The output data is discussed using data from Table XV and information gleaned from an in-depth study of MPAMOD1 output. First, experience gained from using the model to perform this COEA analysis is discussed. Second, the status quo is examined to determine a baseline to measure subsequent scenarios against. Third, an incremental improvement to the status quo, the AIP, is explored. Fourth, the costs and benefits of the new production ORION II are measured against the two previous alternatives. Finally, the effects of cost growth are examined, and SRP and SLEP life extension program effects are documented.

The COEA alternatives are compared on an equal basis. Both the AIP and ORION II alternative place 68 improved ASUW systems in the P-3C fleet.

1. The Model

The model performed all calculations quickly and found good solutions for the given COEA scenarios. The model

is under-utilized in scenarios where top line budget constraints and annual procurement quantities are fixed (since variables are fixed, the model functions more as a large calculator because appropriate trade off decisions are not required). Although it provides the optimal solution given the constraints, its real power is evident in scenarios where it must choose procurement quantities, such as in cost growth Scenarios 3 and 5. In these scenarios it is forced to make trade offs between exceeding the allowable budget, long term effectiveness, and inventory gains.

A more effective approach that would utilize the model's capabilities to the fullest in the other scenarios would be to only specify annual budgets and programs. The model then could choose the best quantities subject to the given constraints.

The model's detailed output, listed previously in Section B.2., provides a wealth of information for program out-year planning. This information could be invaluable to the program manager if used as a long-term planning blueprint for the particular aviation community, regardless of input data complexity.

2. The Status Quo, Scenario 1

Since model input data in this scenario is restricted to current P-3 fleet assets, MPAMOD1 sums O&M and PDM costs in Scenario 1 over a 20 year planning horizon extending from 1993

to 2012. A schedule is provided that retires approximately 10 aircraft per year, leaving 62 in the fleet by year 2012. Average LCC per flight hour is $2,156, and the ASUW MOE is .25 in year 2012.

The status quo is an unacceptable COEA solution. In Scenario 1, a less than graceful attrition of current assets occurs with no replacement. Life cycle costs are relatively high and average ASUW MOE degrades significantly from 0.30 to 0.25 over the planning horizon.

3. The ASUW Improvement Program, Scenario 2

Assuming that the COEA solution must come from the alternatives examined, the AIP (Scenario 2) is analyzed first. For a 14% increase in average LCCs per flight hour, an 80% increase is realized in average ASUW MOE at the 20 year mark of the model planning horizon. This seems like a good trade off until net total MOE is examined. It is low compared to other scenarios because there are only 62 P-3s in the fleet in the year 2012.

This solution still suffers from the degradation of P-3 fleet assets due to forced retirements. The large increase in average ASUW MOE for a modest increase in average LCC per flight hour looks promising, if ways can be found to solve the lack of inventory problem.

4. The New Production Aircraft Program, Scenario 4

The new aircraft program, Scenario 4, looks less than promising. The average 20 year ASUW MOE has increased 136%, but average LCCs per flight hour have increased 91%. When compared to the AIP program, the ratios are even more revealing. The ORION II's cost ratio is 650% greater than the AIP's, while average 20 year MOE ratio only increases 70%.

The ORION II is most dominant in the area of net total MOE. Its fourfold advantage over the AIP is based on the existence of 68 more P-3 aircraft in the inventory in 2012.

5. Cost Growth Effects, Scenarios 3 and 5

Two scenarios are run to examine the effects of the 11% cost growth factor determined in Chapter IV. In Scenario 3, the cost growth factor is applied to the AIP, resulting in a new unit cost of $11.8 million. This is compared to Scenario 2, the same program without the cost growth. In Scenario 5, the cost growth factor is applied to ORION II, resulting in a new unit cost of $107.5 million. This scenario is compared to Scenario 4 as previously described.

In Scenario 3, the effects of the 11% cost growth over the model's 20 year planning horizon is hardly noticeable. Average ASUW MOE declines slightly at the 10 year mark, and total LCCs increase slightly resulting in a modest increase in average LCC per flight hour.

When examining model output in detail, it is apparent how the model accomplished this. MPAMOD1 allowed slight budget increases in four of six AIP production years (exceeding total budget top line), resulting in procurement of four additional units at a net total program cost increase of only $5.8 million (or 0.10% of scenario total costs). Normally the model would be forced to disallow any such top line budget violations, but the model constraints are such that if the benefits accrued from increased fleet ASUW MOEs outweigh the additional costs, the model makes the appropriate trade offs.

Even with such judicious funding use, the model only procured 61 of 68 AIP kits, resulting in the slight ASUW MOE decline at the 10 year mark. For either Scenario 2 or 3, the average ASUW MOEs are the same at the 20 year mark because the model maintains 25 AIP aircraft in the inventory in the year 2012. It has been forced to retire the other AIP aircraft for lack of a suitable life-extension program.

In Scenario 5, cost growth effects are slightly more noticeable. Fleet average ASUW MOEs decline at both the 10 and 20 year mark, and total MOE declines as well. Total LCCs actually decline, but average LCC per flight hour increases slightly. The model recommends purchasing 2 more aircraft, exceeding proposed procurement budgets in years 5 and 10 by 0.42% of scenario total costs. The model recommends exceeding the budget ceiling early in the procurement profile because

accrued benefits exceed costs, and in the last year of the profile because the amount required is small.

In conclusion, cost growth effects of 11% are not significant over the model's planning horizon if model recommended procurement profiles are followed. This is predicated on obtaining very modest additional program funds. The best time to exceed budget limits is early in the program's procurement profile, when accrued long-term benefits outweigh additional costs.

6. SRP and SLEP Programs, Scenarios 6, 7, 8, 9

The best solution for the ASUW mission need is found in the combination of AIP and SRP (Scenario 7) depicted in Figure 1. In Figure 1, the MOE/LCC ratio {Total MOE at the 20 year mark (a measure of both MOE and inventory remaining) divided by Average LCC per Flight Hour} is plotted for all nine scenarios detailed in Table XIV. The MOE/LCC ratio in Scenario 7 increases 281% (from 1.14 to 3.20) over Scenario 2 (AIP without SRP). This option keeps an inventory of 211 P-3s at the 20 year planning mark, causing fleet average ASUW MOE to fall slightly due to the spreading of advanced ASUW capability over the larger fleet.

Benefits accrued from adding the SLEP program (Scenario 9) are minimal at best, with its greatest effect on inventory totals. For a 2% increase in average LCC per flight hour, an additional 26 aircraft at the 20 year planning mark

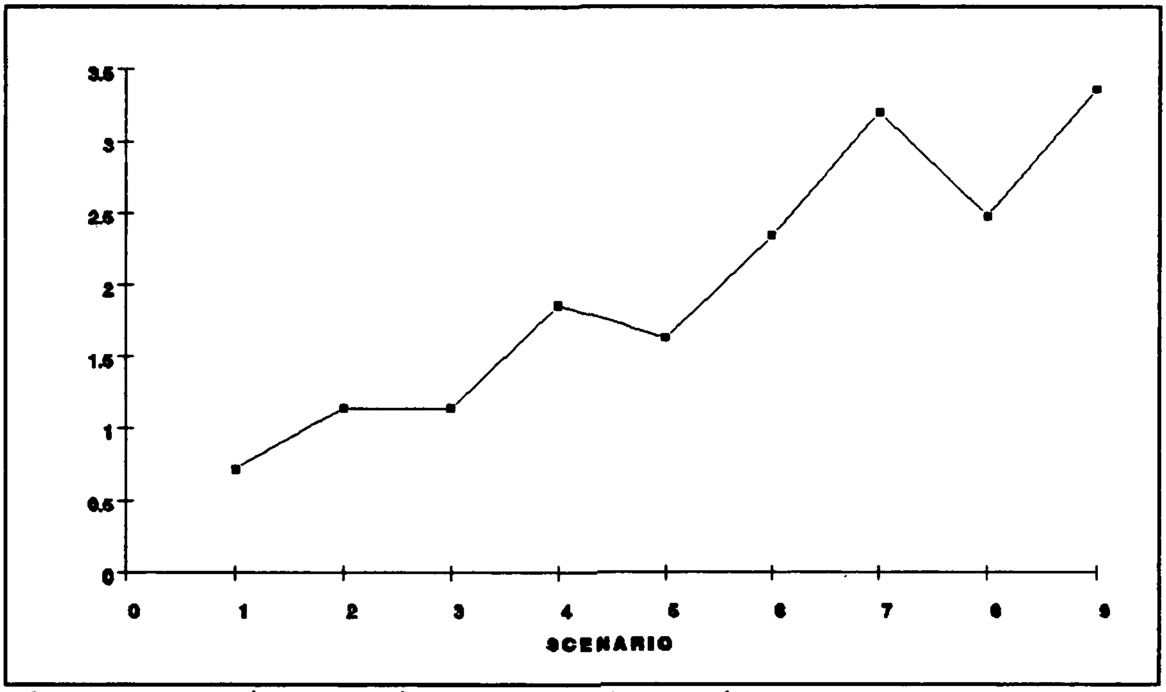

Figure 1 MOE/LCC Ratio for all Scenarios

are realized. MOE/LCC ratio only increases 5%, however, from 3.20 to 3.36. The majority of the life extension benefits have been realized from incorporation of the SRP.

The AIP and SRP combination is much better than the new aircraft option. Costs over baseline increase only 25% (91% for ORION II), and total MOE at the twenty year mark is 13% greater, primarily due to inventory increases.

C. COST EFFECTIVENESS COMPARISON

This section compares the cost effectiveness of a major modification program, the P-3C Update IV, to the new production ORION II. The service lives for the Update IV modified aircraft are not extended, and are significantly

shorter than the service lives of the new production aircraft. The P-3C Update IV was selected because its unit acquisition cost is more than three times greater than the P-3 AIP, allowing for a more realistic comparison. Data for the current P-3 fleet and the AIP are included to exhibit trends, and are presented in Table XVI.

TABLE XVI
COST EFFECTIVENESS COMPARISON DATA

CATEGORY	STAT QUO	P-3 AIP	P-3 UIV	P-3 UIV	P-3 UIV	ORION II
AVG INV/20 YRS	62	62	62	62	62	130
TOT LCC ($MIL)	5063.6	5942.1	7370.1	8016.1	8492.1	13853.9
MODEL UNIT COST		10.5	31.5	41.0	48.0	96.0
TOT INV FLT HRS (MIL)	2.35	2.42	2.42	2.42	2.42	3.36
AVG LCC/FH	2156	2452	3041	3312	3509	4120
COST RATIO		14%	41%	54%	63%	91%
AVG MOE RATIO		80%	124%	124%	124%	136%
NET TOT MOE		12.4	19.2	19.2	19.2	61.2

Unit costs for the P-3C Update IV were first calculated at $31.5 million, and then two cost growth scenarios were considered. The first assumed a cost growth of 30%, raising unit costs to $41 million. The second assumed a "worst case" cost growth of 52%, raising unit costs to $48 million, exactly one half the cost of the new aircraft option. The cost ratio for this "worst case" scenario is 63%, approximately two thirds that of the new aircraft option. This leads to the conclusion that, in this particular scenario, the P-3C Update IV modification program is more cost effective than the ORION

II. Only when the costs of the modification are completely out of control, and experience growth in excess of 50% of the original estimate, will the new aircraft option be viable.

D. FINDINGS

MPAMOD1 is a powerful analytical tool that handled the COEA scenarios very well. It is only limited by the required input data and seems more than capable of handling more complex scenarios if needed. It provided the necessary information to make the proper choice among COEA alternatives presented in this thesis. The detailed output it provides is very useful as a P-3 community long term planning tool.

The COEA alternative that provides the best choice for the ASUW mission is the P-3 AIP modification combined with the SRP life extension program. The COEA status quo, the current P-3 fleet, is unacceptable because ASUW MOE declines significantly over the planning horizon. The new aircraft, the ORION II, provides comparable ASUW MOE gains but average life cycle cost per flight hour over the planning horizon is 3.5 times greater. The SLEP life extension program gains are minimal in terms of increased ASUW MOE, although an additional 26 P-3s are maintained in an active status at the end of the planning horizon through use of the program. The effects of the 11% predicted increase in modification and new production aircraft costs is hardly noticeable and not a factor if MPAMOD1 recommended procurement profiles are followed.

The P-3C Update IV modification proved more cost effective than the ORION II option, except in extreme cases where the cost growth for the modification greatly exceeded 50%. New aircraft programs were significantly less cost effective than the option of modernizing existing platforms, even with the commensurate service life gains, primarily due to the high program costs.

VI. CONCLUSIONS AND RECOMMENDATIONS

As DOD approaches the 21st century, the defense budget in general and the weapon system procurement budget in particular will experience declines. DOD managers must combine a decision making process that uses new analytical tools with accurate preliminary information to effectively allocate remaining resources for weapon system acquisition.

The COEA process described in this thesis provides justification for this type of acquisition decision. Through use of historical cost variances, the process adds quality to the analogous cost estimates used as inputs to a model which implements a proposed program as effectively as possible. DOD managers can constructively analyze the trade offs needed between operational effectiveness and cost, and obtain a better priced, more dependable program that meets all stated mission needs, while preserving scarce budget resources for other programs.

A. CONCLUSIONS

The optimization model, MPAMOD1, was successfully and effectively integrated into the DOD COEA process. MPAMOD1 merges estimated program costs, historical cost variances, and measures of operational effectiveness for each COEA alternative and determines the best implementation plan.

Output data presented allow valid comparisons to determine the best alternative ASUW platform to use in a joint, littoral operation. The solution of choice is an ASUW Improvement Program (AIP) modified P-3 whose service life is extended through the Sustained Readiness Program (SRP) modification. Historical cost variance of P-3 cost estimates proves inconsequential over the model's planning horizon. The model shows that the cost effectiveness of major modification programs becomes doubtful only when modification costs experience cost growth exceeding 50% of original cost estimates.

The COEA process is one method to determine optimum DOD resource allocation decisions needed to effectively use declining defense procurement dollars. The alternative chosen, a P-3 modified by both AIP and SRP programs, costs $85.5 million less per unit to procure than a new production P-3. Its estimated life cycle cost per flight hour is $1,416 less, and it provides nearly the same ASUW effectiveness. This is a productive use of scarce DOD resources.

Even with incorporation of the SRP life extension program, the P-3 fleet reaches the end of its useful life in approximately 20 years. At that time, a new aircraft must be procured to preserve the fleet's MPA capability.

MPAMOD1 provides sufficient information to make the correct COEA decision. The other data that the model provides are invaluable as a long term force planning tool. The

information is of sufficient detail to enhance the planning process, yet still allows decision makers enough flexibility in which to implement the recommended solutions.

The model works best in scenarios where all inputs are not preordained. MPAMOD1's strength is its ability to provide solutions to "what if" drills that have many variables and complex interactions. Its incorporation into the initial stages of program planning is encouraged.

The value of historical cost variance analysis is not apparent in the scenarios examined. Low cost growth experienced in small acquisition programs is not significant over 20 year planning horizons. Solutions recommended by MPAMOD1, such as exceeding procurement budgets by small amounts early in a program's procurement schedule, tended to mitigate problems associated with cost growth.

The effects of life extension programs proves to be very beneficial in the scenarios examined. They provide large payoffs for a small resource investment.

The effects of service life on the cost effectiveness of major modification programs versus new aircraft procurement proves inconsequential as long as modification cost estimates remain reasonable. When cost estimates experience growth exceeding 50%, the cost effectiveness of the modification programs becomes suspect.

B. RECOMMENDATIONS

The COEA process should continue to be used to evaluate all proposed DOD acquisition programs, as current DOD policy recommends. The information gained through evaluation of alternative courses of action proves invaluable for future program planning scenarios. The process is an effective method of husbanding scarce resources and employing them where they will yield the greatest return.

MPAMOD1 would be more valuable in efforts like these if it were easier to use and accessible to more users. To this end, the author echoes past recommendations that encourage its incorporation into software familiar to a majority of potential users. Interfacing MPAMOD1 with a commercially available spreadsheet program is one option.

MPAMOD1 should also be used as far upstream in the planning process as possible. This takes advantage of its computational power and ability to provide solutions to complex planning problems. Using it after decisions have been made on primary variables, such as top line budget amounts and procurement quantities, needlessly restricts solutions.

Although cost variance effects prove negligible in this case, their incorporation into future COEAs is encouraged. With the advent of the RAND Defense System Cost Performance Database, such information is readily available for use.

C. AREAS OF FURTHER STUDY

Further study is required in the area of data required for accurate cost estimates. The most needed items are either parametric cost estimating relationships for use in estimating modernization and new aircraft programs, or cost analyst access to a data base similar to the RAND DSCPD to aid in formulation of analogous cost estimates. Cost information is guarded jealously and currently hard to find. The author recognizes the difficulty of such a recommendation, but such items would only improve the cost estimation process.

A model similar to MPAMOD1 should be designed to evaluate the effective use of Naval Aviation resources in all areas. Such a model could either examine individual aircraft models and variants like P-3s, or whole classes of aircraft such as fighter/attack or helicopters. Naval Aviation is currently at a crossroads, with many critical decisions to make. A model of this type could greatly aid that decision making process.

APPENDIX A. DETAILED COST ESTIMATES

All cost estimates in this appendix are analogous cost estimates. Analogous cost estimates start with an existing systems actual cost, and linking relationships are then developed to estimate the cost of the proposed system. The two systems costed should be similar in nature.

Analogous cost estimates are considered crude and unrefined if the original cost data is suspect or the linking relationships between the two estimates are not developed properly. The more similar the systems are, the better the analogous cost estimate.

The analogous cost estimates in this appendix are not based on source cost data, which was unavailable, but on information pieced together from a wide variety of sources defined in subsequent sections. Although the estimates should be accurate because they are based on similar P-3 systems, without access to the original source material their quality must be suspect. Every effort has been made to make them as accurate as possible.

A. COST ESTIMATE FOR P-3 ASUW IMPROVEMENT PROGRAM

The P-3 AIP cost estimate is an analogous cost estimate that uses historical data obtained from the P-3 Program Office (PMA-290), NAIR-524, and the P-3 Avionics Support Program

Office (ASPO), rounded to the nearest thousand dollars. Based on the historical data, the unit cost of airframe modifications and associated hardware ("A" kit cost) is $970,000; and the installation cost per unit is $1,185,000. The unit cost of equipment ("B" kit cost) for the P-3 AIP cost estimate is summarized in Table XVII.

TABLE XVII
P-3 ASUW IMPROVEMENT PROGRAM B KIT COST ESTIMATE
(THOUSANDS OF FY93 DOLLARS)

SUBSYSTEMS	B KIT
SENSORS	
APS-137 RADAR	1930
ULQ-16 ESM	30
ALR-81 ESM ANT	350
AAS-36 IRDS	80
ELEC-OPTICAL	700
COMMUNICATIONS	
OTCIXS	230
TRE	20
MINI DAMA	350
SATCOM	25
ANDVT	25
ICS MOD	128
DPS/DISPLYS/CTRLS	
CP-2044	100
CHRDS (3)	300
PCHRD	50
PEPS (3)	150
DEPS (2)	20
HARD COPY REC	20
AAR-47	310
TOTALS	4818

Multiplying these costs by the appropriate annual quantities procured in Table XVIII yields the costs entered in the appropriate categories. For example, FY 1994 KIT A costs are derived by multiplying $970,000 x 13 systems for a total cost of $12,610,000.

The total program acquisition cost, by year, is presented in Table XVIII. It is comprised of flyaway cost for quantity of units purchased (including NRE), support and equipment and spares. Unit costs are also calculated.

TABLE XVIII
P-3 ASUW IMPROVEMENT TOTAL PROGRAM COST
(THOUSANDS OF FY93 DOLLARS)

YEAR/QTY	FY94/13	FY95/13	FY96/20	FY97/20	FY98/2	TOTAL/68	UNIT COST
CATEGORIES							
AIRFRAME	28015	28015	43100	43100	4310	146540	
KIT A	12610	12610	19400	19400	1940	65960	
INSTALL	15405	15405	23700	23700	2370	80580	
AVIONICS KIT B	62634	62634	96360	96360	9636	327624	
NRE	35000	0	0	0	0	35000	
FLYAWAY	125649	90649	139460	139460	13946	509164	7488
GSE	13599	13839	6530	9219	0	43188	
TRNG EQ & OTH	32617	34236	21792	26149	5512	120306	
WEAPON SYS	171865	138725	167782	174828	19458	672658	9892
SPARES	14473	14599	22660	22881	2310	76923	
PROCUREMENT	186338	153324	190442	197709	21769	749580	11023
ACQUISITION	186338	153324	190442	197709	21769	749580	11023

The primary AIP cost estimate unknown is NRE costs. NRE costs ranged from a $12 million contractor estimate to a $50 million government estimate. This estimate's $35.0 million NRE

figure is based on the program's Statement of Work (SOW), which requires minimum software integration for program implementation, and the program's acquisition strategy of "streamlining". Costs calculated in Table XVIII are summarized in Table IV, Chapter III.

B. COST ESTIMATE FOR P-3C UPDATE IV

The P-3C Update IV cost estimate is an analogous cost estimate that is presented in thousands of dollars. System description and unit flyaway "B" kit cost are presented in Table XIX.

Since a significant portion of Update IV is composed of new production systems, the cost estimate contains more elements of uncertainty. The cost estimate is based on historical data obtained from PMA-290, and, despite appearances, the data is judged to be no more accurate than the P-3 AIP cost estimate presented previously.

The "A" kit cost for the P-3C Update IV is $3,779,600. The installation cost is $3,237,400.

TABLE XIX
P-3 UPDATE IV UNIT FLYAWAY COST ESTIMATE
(THOUSANDS OF FY93 DOLLARS)

SUBSYSTEM	B KIT COST
COMMUNICATIONS	1587.0
ARC-187 UHF RADIO(2)	51.4
ARQ-50 HF RADIO (2)	585.9
TE-237 DATA LINK MODEM	58.6
ARC-182 UHF/VHF RADIO	54.6
AIC-39(V)1 ICS	578.7
USQ-42(V)3 SATCOM	248.8
RADIO DELAY RELAY BOX	9.0
NAVIGATION	70.1
LTN-211 OMEGA	62.2
ARN-151(V)3 GPS	7.9
NON-ACOUSTIC	2791.8
APS-137(V)5 ISAR RADAR	1469.7
ASQ-206 DIGITAL MAD	244.1
ALR-66(V)5 ESM	1019.5
ISAR INSTALLATION (VTR)	58.5
ACOUSTIC	4056.3
UYS-2A PROCESSOR	1953.1
CP-2021 AIU	309.3
AQR-185 SONO RECEIVER	1020.4
HIGH DENSITY DATA RCDR	773.5
DATA PROCESSING	2817.2
CP-2032 DP/DGU	1887.8
CHRD (5)	294.3
PEP (6)	482.9
PCHRD	75.5
SCP	76.7
SUBTOTAL	11322.4
PROFIT (11.5%)	1302.1
TOTAL	12624.5

The total program acquisition cost, by year, is presented in Table XX. It is composed of flyaway cost for quantity of units purchased (including NRE), support and training equipment, spares, and RDT&E. A program acquisition unit cost is also calculated.

TABLE XX
P-3 UPDATE IV TOTAL PROGRAM COST
(THOUSANDS OF FY93$)

FY/QTY	94/8	95/10	96/10	97/10	98/10	99/10	00/10	TOTAL	UNIT COST
CATEGORY									
AIRFRAME	56136	70170	70170	70170	70170	70170	70170	477156	
AFC KIT	30237	37796	37796	37796	37796	37796	37796		
INSTALL	25899	32374	32374	32374	32374	32374	32374		
AVIONICS	100996	126245	126245	126245	126245	126245	126245	858466	
NRE	147000							147000	
FLYAWAY	304132	196415	196415	196415	196415	196415	196415	1482622	21803
TRN EQ	133642	118463	117152	75341	69161	42758	29113	585630	
WEAPON	437774	314878	313567	271756	265576	239173	225528	2068252	30415
SPARES	29200	23200	33900	55400	50200	21100	10000	223000	
PROCURE	466974	338078	347467	327156	315776	260273	235528	2291252	33694
RDT&E	0	0	0	0	0			319000	
MILCON	0	0	0	0	0			0	
ACQUIS	466974	338078	347467	327156	315776	260273	235528	2610252	38386

Total costs and unit costs calculated in Table XX are displayed in Table VII, Chapter III.

C. NEW PRODUCTION P-3 COST ESTIMATE

The ORION II's analogous cost estimate is based on installed systems that are currently flying in fleet P-3s. The most uncertainty surrounding the estimate concerns the new airframe modifications, especially the fuselage "stretch" and the provisions for inflight refueling. The cost estimate is based on historical data obtained from PMA-290 and NAIR-524. The aircraft unit cost is presented in Table XXI.

TABLE XXI
ORION II UNIT FLYAWAY COST
(MILLIONS OF FY93 DOLLARS)

CATEGORY	COST	
AIRFRAME		47.3
ENGINES/ACCESSORIES		7.8
ARMAMENT AND OTHER		0.4
NRE		4.8
ELECTRONICS/COMMUNICATIONS		18.0
COMMUNICATIONS	3.0	
NAVIGATION	2.1	
NON-ACOUSTIC	5.8	
ACOUSTIC	4.3	
PROCESSING/DISPLAY	2.7	
TOTAL		78.3

The total program acquisition cost, by year, is presented in Table XXII. It is composed of flyaway cost for quantity of units purchased (including NRE), support and training equipment, spares, and RDT&E. Unit costs are also provided.

Total costs and unit costs calculated in Table XXII are displayed in Table VI, Chapter III.

TABLE XXII
ORION II TOTAL PROGRAM COST
(MILLIONS OF FY93 DOLLARS)

FY/QTY	96/6	97/12	98/12	99/12	00/12	01/12	02/2	TOTAL/68	UNIT COST
CATEGORY									
AIRFRAME	673.6	581.8	479.2	467.9	468.1	469.6	78.5	3218.7	
ENG/ACC	58.8	109.6	87.9	87.1	86.2	84.4	13.9	527.9	
ARM/OTH	2.7	4.8	4.6	4.5	4.5	4.4	0.7	26.2	
ELEC/COMM	108.2	216.5	216.5	216.5	216.5	216.5	36.1	1226.8	
NRE	326.7							326.7	
FLYAWAY	1170.0	912.7	788.2	776.0	775.3	774.9	129.2	5326.3	78.3
GSE	71.2	83.0	75.2	73.7	74.3	73.7	12.0	463.1	
TRG/OTH	182.1	129.5	120.7	82.8	83.7	82.9	13.5	695.2	
WEP SYS	1423.3	1125.2	984.1	932.5	933.3	931.5	154.7	6484.6	95.4
SPARES	116.9	75.2	62.9	38.4	38.3	37.7	6.1	375.5	
PROCURE	1540.2	1200.4	1047.0	970.9	971.6	969.2	160.8	6860.1	100.9
RDT&E								195.6	
ACQ	1540.2	1200.4	1047.0	970.9	971.6	969.2	160.8	7055.7	103.8

APPENDIX B. HISTORICAL COST DATA

Three completed acquisition programs are sources for P-3 historical cost data. The completed program data was collected from the program's terminal SAR. In addition, a mythical aircraft, the P-11, is created using Hess and Romanoff's CER for all aircraft mission types [Ref. 23]. The P-11 calculations are presented in the following paragraph.

The P-11 calculations for 68 aircraft are as follows:

Aircraft Empty Weight (EW) - 82,000 lb

Aircraft Maximum Speed (SP) - 410 kn

Total program cost for 100 aircraft (thousands of $1977):

$$= 2.57\ (EW^{.798})(SP^{.736})$$

$$= \$1,795,317.51$$

Total program cost for 68 aircraft (thousands of $1977):

$$= \text{COST}(100) * [(68/100)]^{.401}$$

$$= 1,795,317.51 * .86$$

$$= \$1,538,074.39$$

Convert to 1993 dollars:

$$= (1,538,074.39/.3835)*1000$$

$$= \$4,010,624,222$$

Average unit airframe cost:

$$= 4,010,624,222/68 = \$58,979,768$$

Engine costs are $6.64 million and avionics costs are $20 million. Armament and other costs are $0.2 million. NRE costs,

added to the airframe cost category, total $270 million. Support equipment and spares cost is 20% and 8% of total flyaway cost, respectively. The cost of RDT&E is 15% of flyaway, and military construction is negligible.

The historical cost data is summarized in Table XXIII. It also is presented in Table IX, Chapter III.

TABLE XXIII
P-3 HISTORICAL COST DATA
(MILLIONS OF FY93 DOLLARS)

TYPE A/C	P-3C UIII	P-3C UIII	P-7A	P-11
QUANTITY	80	32	125	68
PROG START	1984	1984	1989	1993
CATEGORIES				
AIRFRAME	1976.9	732.7	3167.6	4005.2
ENG/ACC	339.3	114.6	634.2	451.5
ELEC/COMM	1179.4	380.3	1393.7	1360.0
ARM/OTHER	28	9	12.3	13.6
FLYAWAY COST	3523.6	1236.6	5207.8	5830.3
GSE	248.4	98.5	183.1	291.5
TRG EQ/OTH	762.7	312.4	478.1	874.6
% OF FLYAWAY (1)	29%	33%	13%	20%
WEAP SYS COST	4534.7	1647.5	5869	6996.4
SPARES	85.1	27.8	649.6	466.4
% OF FLYAWAY	2%	2%	12%	8%
PROCUREMENT COST	4619.8	1675.3	6518.6	7462.8
RDT&E	374.7	77.1	969.3	874.6
% OF FLYAWAY (2)	11%	6%	19%	15%
MILCON	3.5	12	5.5	0
ACQUISITION COST	4998	1764	7493	8337

Notes: (1) (GSE + TRG EQ/OTH COSTS)/FLYAWAY COSTS
(2) RDT&E COSTS/FLYAWAY COSTS

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